VOLUME II

ZDOC/95FINAL/APP

ZERO DISCHARGE ORGANIC COATINGS

Powder Paint - UV Curable Paint - E-Coat

Final Technical Report
June 1993 - June 1995

APPENDIXES

Sponsored by
Advanced Research Projects Agency
Defense Sciences Office
Environmental Technology Research and Development Initiative
ARPA Order No. 9328/06
Issued by ARPA/CMO under Contract #MDA972-93-C-0020

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APPENDIX A

IR Cure Evaluation Evaluation Plan

Proposed Powder Coating IR Cure Test Plan

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INTRODUCTION

The Zero Discharge Organic Coatings (ZDOC) project funded under the Advanced Research Projects Agency (ARPA) includes an effort to evaluate and develop infrared (IR) curing techniques for powder coatings. IR curing is attractive because of increased throughput as compared to conventional thermal methods, and because it may offer certain advantages in specific applications. For example, IR curing might lead to less substrate heating, which is a concern with some high-performance materials (such as aluminum in heat-sensitive tempers) used in industry.

IR curing of coating materials, including powders, has been in practice for some time. However, very little experimental work has been documented in the open literature on IR cured topcoats under the demanding performance requirements of the aerospace industry. As part of the ZDOC project IR cured powder coatings will be evaluated against criteria commonly applied to conventionally cured aerospace coatings.

EXPERIMENTAL APPROACH

The test plan consists of three phases:

I. Determine feasibility of IR curing powders, including extent (completeness) of cure.
II. Evaluate substrate heating effects.
III. Perform comparative testing against conventionally cured powders and other coatings.

In Phase I the characteristics of powders cured with IR energy will be evaluated. Common laboratory techniques (including differential scanning calorimetry [DSC] and solvent resistance) will be used to determine the completeness of cure. The effect of coating color and gloss will be determined. In addition, an assessment of commercially available IR curing systems will be made with on-site visits to suppliers and current users to cure a variety of powder materials.

Phase II will address substrate heating concerns. With conventional thermal curing techniques the substrate is nominally heated to the cure temperature of the coating. IR curing, primarily because of its speed, may result in less heating of the substrate. This may be an advantage with certain metallic and composite substrates. The heat effect will be investigated using thermocouples installed at appropriate locations during IR curing of powders. Differences in peak temperatures will be determined as a function of color and gloss.

Finally, Phase III will consider performance aspects of IR cured powder coatings. A standard aerospace topcoat (aliphatic polyurethane in accordance with MIL-C-83286) will be taken as a baseline, and samples of IR cured powders tested against the requirements therein. Performance relative to thermally cured powders will also be evaluated. Since experimental results are already available for MIL-C-83286 coatings and thermally cured powders (Reference 1) testing will be performed on IR cured samples only.

MATERIALS

Substrate -- unless required by a specific test, the substrate will be 2024-T4 aluminum panels conversion coated in accordance with MIL-C-5541 will be used. Panel size and thickness will be determined by the test being run. Wherever feasible a standard panel of 3 inches by 10 inches, 0.020 inch thick will be used. It is expected that other materials addressed in the ZDOC project (such as composites) will also be used as test substrates.

Coating -- the primary coating used in this test plan will be an epoxy powder currently used on a number of production programs at Hughes Missile Systems Company (HMSC). This is a low-gloss, medium gray topcoat that has proven suitable for use on high-performance aerospace weapons systems. Other powders, especially in other colors and gloss ranges, will be utilized as the test program requires.

Other -- certain materials may be required from time to time to complete specific tests or to perform particular evaluations. For example, the tape adhesion test requires a tape with a closely controlled adhesion value. In these cases materials stocked in the Components and Materials Engineering Department (C&M) laboratories will be utilized.

Equipment - The equipment required for the majority of tests is available in the C&M labs. Other facilities, both within HMSC and external, will be used as appropriate.

EXPERIMENTAL METHODS

For Phases I and II experimental methods will be developed which will provide the data desired with a minimum of time, effort, and cost. In Phase III tests defined in MIL-C-83286 will be performed. Details on these can be found in the specification; a summary of test goals and procedures can be found in Reference 1. A test matrix is provided in Table 1.

REFERENCES

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ZDOC POWDER COATING
IR CURE TEST MATRIX

TEST	TEST METHOD	PANEL TYPE 1	PANEL TYPE 2	PANEL TYPE 3	PANEL TYPE 4
SALT FOG, 50 HOUR	ASTM B 117	X			
SALT FOG, 500 HOUR	ASTM B 117	X			
SALT FOG, 1000 HOUR	ASTM B 117	X			
HUMIDITY (30 DAY)	FTMS 141, METHOD 6201	X			
IMPACT FLEXIBILITY	FTMS 141, METHOD 6226 (ASTM D 2794)			X	
CHEMICAL RESISTANCE	MIL-C-83286, PARAGRAPH 3.7.3.5; ASTM D 1308	X			
PENCIL HARDNESS	ASTM D 3363	X			
ADHESION, WET TAPE	FTMS 141, METHOD 6301	X			
ADHESION, DRY TAPE	[STANDARD LABORATORY PRACTICE]	X			
GLOSS, 60 DEGREE SPECULAR	FTMS 141, METHOD 6101	X			
COLOR	FTMS 141, METHOD 4250	X			
HEAT RESISTANCE	MIL-C-83286, PARAGRAPH 3.7.3.3		X		
LOW TEMPERATURE FLEXIBILITY	FTMS 141, METHOD 6222 (ASTM D 1737)		X		
ABRASION RESISTANCE	ASTM D 4060				X
PANEL TYPE 1: 2024-T3, 3x6x0.020					
PANEL TYPE 2: 2024-T0, 3x6x0.020					
PANEL TYPE 3: 2024-T0,4x6x0.020					
PANEL TYPE 4: STEEL, 4x4x0.250					

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APPENDIX B

References Regarding Aluminum Corrosion and Aluminum Inhibitors

References regarding aluminum corrosion and aluminum inhibitors

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APPENDIX C

Electrocoat Bath and Paste Formulations

JBA109 E'coat with KW-84.					
	JBA109	Bath-01			
% Non-Volatiles =	67.25%	20.60%			
P/B Ratio =	2.9071	0.2729			
Inhibitor P/B Ratio =	1.6322	0.1532			
E/G Resin Ratio =	NA	9.65			
KW-84 is Tayca Corp. Corrosion Inhibitor K-White 84.					
Pigment Paste Formula:	JBA109				
Ingredient	Weight	Paste	Non-Volatile	Resin	
Mill Base	(gram)	Weight %	Weight	Weight	
Grind Resin	166.37	45.90%	62.39	62.39	
Antifoam	4.99	1.38%	0.00	0.00	
Butyl Cellosolve	3.15	0.87%	0.00	0.00	
DDI Water	6.57	1.81%	0.00	0.00	
Mill Base Total	181.08	49.96%			
Pigments and Powders					
TiO2	33.98	9.38%	33.98	0.00	
KW-84	101.83	28.09%	101.83	0.00	
Clay	36.49	10.07%	36.49	0.00	
Black	0.35	0.10%	0.35	0.00	
Catalyst	8.72	2.41%	8.72	0.00	
Pigment Total	181.37	50.04%			
Process Additions					
DDI Water	0.00	0.00%	0.00	0.00	
Butyl Cellosolve	0.00	0.00%	0.00	0.00	
Letdown DDI	0.00	0.00%	0.00	0.00	
Paste Total	362.45	100.00%	243.76	62.39	
Bath JBA109 - 01					
	wt.	wt. nv	wt. Resin		
Resin Emulsion	426.29	146.64	146.64		
DDI Water	485.50	0.00	0.00		
Pigment Paste	88.27	59.36	15.19		
Bath Totals	1000.06	206.01	161.84		
Bath %NV =	20.60%	Emulsion/Grind Resin Ratio =			9.65
Bath P/B Ratio =	0.2729			Bath PVC =	
Inhibitor P/B Ratio =	0.1532		Inhibitor Bath PVC =		
Inhibitor Bath Wt. % =	2.48%				
Inhibitor Film Wt. % =	12.04%				

JBA073 E'coat with MW-101.					
		Paste	Bath - 01		
% Non-Volatiles =		62.62%	20.21%		
	P/B Ratio =	2.9008	0.2566		
Inhibitor P/B Ratio =		1.6317	0.1443		
E/G Resin Ratio =		NA	10.31		
MW-101 is Sherwin-Williams Corrosion Inhibitor Moly White 101.					
Pigment Paste Formula:		JBA073			
	Ingredient	Weight	Paste	Non-Volatile	Resin
	Mill Base	(gram)	Weight %	Weight	Weight
	Grind Resin	166.37	42.81%	62.39	62.39
	Antifoam	3.14	0.81%	0.00	0.00
	Butyl Cellosolve	3.16	0.81%	0.00	0.00
	DDI Water	6.52	1.68%	0.00	0.00
	Mill Base Total	179.19	46.11%		
	Pigments and Powders				
	TiO2	33.96	8.74%	33.96	0.00
	MW-101	101.80	26.20%	101.80	0.00
	Clay	36.20	9.32%	36.20	0.00
	Black	0.34	0.09%	0.34	0.00
	Catalyst	8.68	2.23%	8.68	0.00
	Pigment Total	180.98	46.57%		
	Process Additions				
	DDI Water	21.39	5.50%	0.00	0.00
	Butyl Cellosolve	4.55	1.17%	0.00	0.00
	Acetic Acid	2.51	0.65%		
	Letdown DDI	0.00	0.00%	0.00	0.00
	Paste Total	388.62	100.00%	243.37	62.39
Bath JBA073 - 01					
		wt.	wt. nv	wt. Resin	
	Resin Emulsion	341.01	117.31	117.31	
	DDI Water	388.38	0.00	0.00	
	Pigment Paste	70.90	44.40	11.38	
	Bath Totals	800.29	161.71	128.69	
Bath %NV =		20.21%	Emulsion/Grind Resin Ratio =		10.31
Bath P/B Ratio =		0.2566		Bath PVC =	
Inhibitor P/B Ratio =		0.1443		Inhibitor Bath PVC =	
Inhibitor Bath Wt. % =		2.32%			
Inhibitor Film Wt. % =		11.49%			

JBA077 E'coat with Phos Plus.					
	Paste	Bath - 01			
% Non-Volatiles =	65.39%	20.44%			
P/B Ratio =	2.9005	0.2665			
Inhibitor P/B Ratio =	1.6318	0.1499			
E/G Resin Ratio =	NA	9.88			
Phos Plus is Mineral Pigment Corrosion Inhibitor Phos Plus.					
Pigment Paste Formula:	JBA077				
Ingredient	Weight	Paste	Non-Volatile	Resin	
Mill Base	(gram)	Weight %	Weight	Weight	
Grind Resin	166.38	44.71%	62.39	62.39	
Antifoam	3.14	0.84%	0.00	0.00	
Butyl Cellosolve	3.12	0.84%	0.00	0.00	
DDI Water	6.46	1.74%	0.00	0.00	
Mill Base Total	179.10	48.12%			
Pigments and Powders					
TiO2	33.93	9.12%	33.93	0.00	
PhosPlus	101.81	27.36%	101.81	0.00	
Clay	36.20	9.73%	36.20	0.00	
Black	0.35	0.09%	0.35	0.00	
Catalyst	8.68	2.33%	8.68	0.00	
Pigment Total	180.97	48.63%			
Process Additions					
DDI Water	9.65	2.59%	0.00	0.00	
Butyl Cellosolve	2.44	0.66%	0.00	0.00	
Letdown DDI	0.00	0.00%	0.00	0.00	
Paste Total	372.16	100.00%	243.36	62.39	
Bath JBA077 - 01					
	wt.	wt. nv	wt. Resin		
Resin Emulsion	426.25	146.63	146.63		
DDI Water	485.58	0.00	0.00		
Pigment Paste	88.48	57.86	14.83		
Bath Totals	1000.31	204.49	161.46		
Bath %NV =	20.44%	Emulsion/Grind Resin Ratio =			9.88
Bath P/B Ratio =	0.2665			Bath PVC =	
Inhibitor P/B Ratio =	0.1499		Inhibitor Bath PVC =		
Inhibitor Bath Wt. % =	2.42%				
Inhibitor Film Wt. % =	11.84%				

JBA114 E'coat with Sicron-RZ						
		JBA114	Bath-01			
% Non-Volatiles =		34.27%	19.44%			
	P/B Ratio =	0.7333	0.2054			
Inhibitor P/B Ratio =		0.5435	0.0149			
E/G Resin Ratio =		NA	9.96			
Sicron-RZ is BASF Pigments Corrosion Inhibitor Sicron-RZ.						
Pigment Paste Formula:		JBA114				
	Ingredient	Weight	Paste	Non-Volatile	Resin	
	Mill Base	(gram)	Weight %	Weight	Weight	
	Grind Resin	166.47	52.72%	62.43	62.43	
	Antifoam	3.13	0.99%	0.00	0.00	
Butyl Cellosolve		3.14	0.99%	0.00	0.00	
	DDI Water	6.46	2.05%	0.00	0.00	
Mill Base Total		179.20	56.75%			
Pigments and Powders						
	TiO2	0.00	0.00%	0.00	0.00	
	Sicron-RZ	33.93	10.75%	33.93	0.00	
	Clay	9.63	3.05%	9.63	0.00	
	Black	0.00	0.00%	0.00	0.00	
	Catalyst	2.22	0.70%	2.22	0.00	
Pigment Total		45.78	14.50%			
Process Addtions						
	DDI Water	53.37	16.90%	0.00	0.00	
Butyl Cellosolve		19.48	6.17%	0.00	0.00	
Letdown DDI		17.94	5.68%	0.00	0.00	
	Paste Total	315.77	100.00%	108.21	62.43	
Bath JBA114 - 01						
		wt.	wt. nv	wt. Resin		
Resin Emulsion		426.27	146.64	146.64		
	DDI Water	485.58	0.00	0.00		
JBA114 Paste		22.30	7.64	4.41		
JBA099 Paste		66.29	40.22	10.31		
	Bath Totals	1000.44	194.50	161.36		
Bath %NV =		19.44%	Emulsion/Grind Resin Ratio =			9.96
Bath P/B Ratio =		0.2054			Bath PVC =	
Inhibitor P/B Ratio =		0.0149		Inhibitor Bath PVC =		
Inhibitor Bath Wt. % =		0.24%				
Inhibitor Film Wt. % =		1.23%				

JBA069 E'coat With SZP-391.						
		Paste	Bath - 01			
% Non-Volatiles =		66.04%	20.54%			
	P/B Ratio =	2.9042	0.2714			
Inhibitor P/B Ratio =		1.6344	0.1527			
E/G Resin Ratio =		NA	9.70			
SZP-391 is Halox Corrosion Inhibitor SZP-391.						
Pigment Paste Formula:		JBA069				
	Ingredient	Weight	Paste	Non-Volatile	Resin	
	Mill Base	(gram)	Weight %	Weight	Weight	
	Grind Resin	166.37	45.11%	62.39	62.39	
	Antifoam	3.13	0.85%	0.00	0.00	
Butyl Cellosolve		3.14	0.85%	0.00	0.00	
	DDI Water	6.46	1.75%	0.00	0.00	
Mill Base Total		179.10	48.56%			
Pigments and Powders						
	TiO2	34.03	9.23%	34.03	0.00	
	SZP-391	101.97	27.65%	101.97	0.00	
	Clay	36.20	9.82%	36.20	0.00	
	Black	0.43	0.12%	0.43	0.00	
	Catalyst	8.56	2.32%	8.56	0.00	
Pigment Total		181.19	49.13%			
Process Additions						
	DDI Water	8.53	2.31%		0.00	
Butyl Cellosolve		0.00	0.00%		0.00	
Letdown DDI		0.00	0.00%		0.00	
	Paste Total	368.82	100.00%	243.58	62.39	
Bath JBA069 - 01						
		wt.	wt. nv	wt. Resin		
Resin Emulsion		426.28	146.64	146.64		
	DDI Water	485.51	0.00	0.00		
Pigment Paste		89.35	59.01	15.11		
	Bath Totals	1001.14	205.65	161.75		
Bath %NV =		20.54%	Emulsion/Grind Resin Ratio =			9.70
Bath P/B Ratio =		0.2714			Bath PVC =	
Inhibitor P/B Ratio =		0.1527			Inhibitor Bath PVC =	
Inhibitor Bath Wt. % =		2.47%				
Inhibitor Film Wt. % =		12.01%				

JBB043 E'coat with ZMP.							
		JBB043	Bath - 01				
% Non-Volatiles =		55.74%	20.02%				
	P/B Ratio =	2.9003	0.2494				
Inhibitor P/B Ratio =		1.6318	0.1403				
E/G Resin Ratio =		NA	10.63				
ZMP is Heucotech Ltd. Corrosion Inhibitor ZMP.							
Pigment Paste Formula:		JBB043					
	Ingredient	Weight	Paste	Non-Volatile	Resin	Bath	Film
	Mill Base	(gram)	Weight %	Weight	Weight	Weight %	Weight %
2nd Batch	Grind Resin	155.24	23.70%	93.61	93.61	0.022848	0.068828
	Acetic Acid	0.76	0.12%	0.00	0.00	0.000112	0
	Antifoam	4.69	0.72%	0.00	0.00	0.00069	0
	Butyl Cellosolve	4.69	0.72%	0.00	0.00	0.00069	0
	DDI Water	102.99	15.72%	0.00	0.00	0.015158	0
	Mill Base Total	268.37	40.97%				
	Pigments and Powders						
	TiO2	50.91	7.77%	50.91	0.00	0.007493	0.037432
	ZMP	152.75	23.32%	152.75	0.00	0.022481	0.112311
	Clay	54.29	8.29%	54.29	0.00	0.00799	0.039917
	Black	0.50	0.08%	0.50	0.00	7.36E-05	0.000368
	Catalyst	13.05	1.99%	13.05	0.00	0.001921	0.009595
	Pigment Total	271.50	41.45%				
	Process Additions						
	DDI Water	15.28	2.33%	0.00	0.00	0.002249	0
	Butyl Cellosolve	47.05	7.18%	0.00	0.00	0.006925	0
	Letdown DDI	52.79	8.06%	0.00	0.00	0.007769	0
	Paste Total	654.99	1	365.11	93.61		
	Bath - 01						
		wt.	wt. nv	wt. Resin			
	Resin Emulsion	397.51	136.74	136.74			0.731549
	DDI Water	446.29	0.00	0.00			0
	Pigment Paste	90.02	50.18	12.87			
	Glacial Acetic Acid	0.23	0.00	0.00			
	Bath Totals	933.82	186.92	149.61			1
	Bath %NV =	20.02%	Emulsion/Grind Resin Ratio =			10.63	
	Bath P/B Ratio =	0.2494			Bath PVC =		
	Inhibitor P/B Ratio =	14.03%		Inhibitor Bath PVC =			
	Inhibitor Bath Wt. % =	2.25%					
	Inhibitor Film Wt. % =	11.23%					

JBB039 E'coat with Hsil - ZW.						
		JBB039	Bath - 01			
% Non-Volatiles =		58.50%	20.03%			
	P/B Ratio =	2.8991	0.2491			
Inhibitor P/B Ratio =		1.6306	0.1401			
E/G Resin Ratio =		NA	10.64			
Hsil-ZW is Heucotech Ltd. Corrosion Inhibitor Heucosil ZW.						
Pigment Paste Formula:		JBB039				
	Ingredient	Weight	Paste	Non-Volatile	Resin	
	Mill Base	(gram)	Weight %	Weight	Weight	
2nd Batch	Grind Resin	155.29	24.88%	93.64	93.64	
	Acetic Acid	1.04	0.17%	0.00	0.00	
	Antifoam	4.77	0.76%	0.00	0.00	
	Butyl Cellosolve	4.69	0.75%	0.00	0.00	
	DDI Water	103.01	16.50%	0.00	0.00	
	Mill Base Total	268.80	43.07%			
	Pigments and Powders					
	TiO2	50.91	8.16%	50.91	0.00	
	Hsil-ZW	152.69	24.46%	152.69	0.00	
	Clay	54.30	8.70%	54.30	0.00	
	Black	0.52	0.08%	0.52	0.00	
	Catalyst	13.05	2.09%	13.05	0.00	
	Pigment Total	271.47	43.49%			
	Process Additions					
	DDI Water	18.42	2.95%	0.00	0.00	
	Butyl Cellosolve	5.69	0.91%	0.00	0.00	
	Letdown DDI	59.79	9.58%	0.00	0.00	
	Paste Total	624.17	1	365.11	93.64	
Bath JBB039 - 01						
		wt.	wt. nv	wt. Resin		
	Resin Emulsion	417.52	143.63	143.63		
	DDI Water	472.52	0.00	0.00		
	Pigment Paste	90.00	52.65	13.50		
	Glacial Acetic Acid	2.39	0.00	0.00		
	Bath Totals	980.04	196.27	157.13		
Bath %NV =		20.03%	Emulsion/Grind Resin Ratio =			10.64
Bath P/B Ratio =		0.2491			Bath PVC =	
Inhibitor P/B Ratio =		14.01%		Inhibitor Bath PVC =		
Inhibitor Bath Wt. % =		2.25%				
Inhibitor Film Wt. % =		11.22%				

ZERO DISCHARGE ORGANIC COATINGS
Powder Paint - UV Curable Paint - E-Coat

APPENDIX D

Electrocoat EIS Tables and Figures

```
Pathname    : b:\
Filename    : 14R10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388        2.71
Ambient:  -700
Electrode:  7.5440E+00

Freq. range:  1.000E+00 -  1.000E+05 Herz
Data set    :     25 frequencies

CircuitCode: R(Q[R(QR)])

Chi-Squared:  1.29E-04

Resistance      - 1=  6.644E+02       8.11 %   [ohm]
C-P Elmnt, Yo-  2=  4.307E-10       1.34 % ["mho"]
Freq power, n-  2=  0.9679          0.13 %
Resistance      - 3=  2.305E+07       3.86 %   [ohm]
C-P Elmnt, Yo-  4=  5.306E-09      10.81 % ["mho"]
Freq power, n-  4=  0.7033          6.64 %
Resistance      - 5=  2.463E+07       8.11 %   [ohm]
```

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5
R- 1:	1.00						
Q- 2:	-0.36	1.00					
n- 2:	0.38	-0.98	1.00				
R- 3:	-0.23	0.69	-0.65	1.00			
Q- 4:	0.04	-0.12	0.11	-0.43	1.00		
n- 4:	-0.15	0.45	-0.42	0.84	-0.83	1.00	
R- 5:	-0.17	0.53	-0.49	0.85	-0.77	0.96	1.00

Table 19: Computer printout of fit of 2 time constant model to data obtained at -700 mV (REF). See Figure 18 for plot illustrating fit.

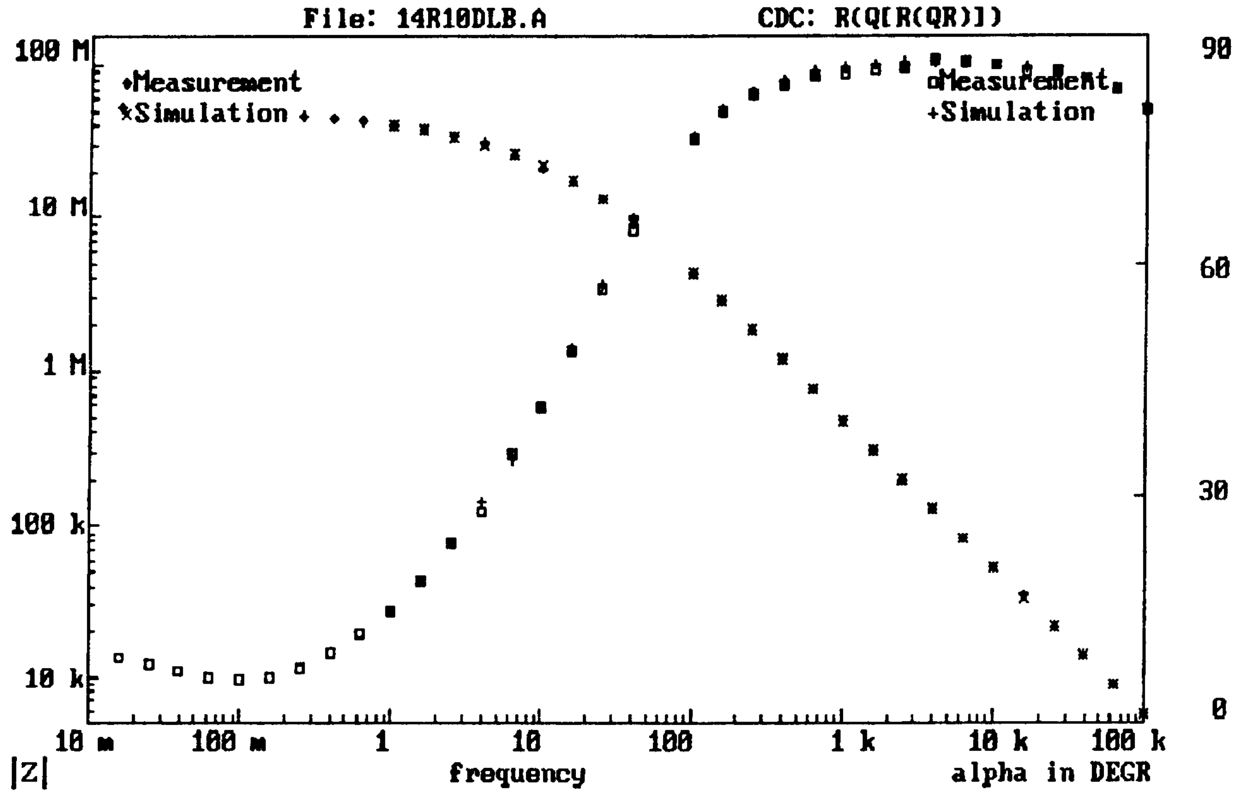

Figure 18: Fit of data from Table 19.

```
Pathname    : b:\
Filename    : LF10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388        2.71
Ambient:   -700
Electrode:  7.5440E+00

Freq. range:  1.000E+00 -  1.000E+05 Herz
Data set    :    25 frequencies

CircuitCode: R(Q[R(QR)])

Chi-Squared:  1.05E-04

Resistance     - 1=  6.632E+02      7.36 %    [ohm]
C-P Elmnt, Yo- 2=  4.318E-10      1.21 % ["mho"]
Freq power, n- 2=  0.9676         0.12 %
Resistance     - 3=  2.287E+07      3.53 %    [ohm]
C-P Elmnt, Yo- 4=  4.921E-09      9.31 % ["mho"]
Freq power, n- 4=  0.7062         5.64 %
Resistance     - 5=  2.621E+07      6.91 %    [ohm]
```

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5
R- 1:	1.00						
Q- 2:	-0.36	1.00					
n- 2:	0.38	-0.98	1.00				
R- 3:	-0.23	0.69	-0.65	1.00			
Q- 4:	0.04	-0.12	0.11	-0.43	1.00		
n- 4:	-0.15	0.45	-0.41	0.84	-0.83	1.00	
R- 5:	-0.17	0.53	-0.49	0.85	-0.78	0.95	1.00

Table 20: Computer printout of fit of 2 time constant model to data obtained at -700 mV (REF). See Figure 19 for plot illustrating fit.

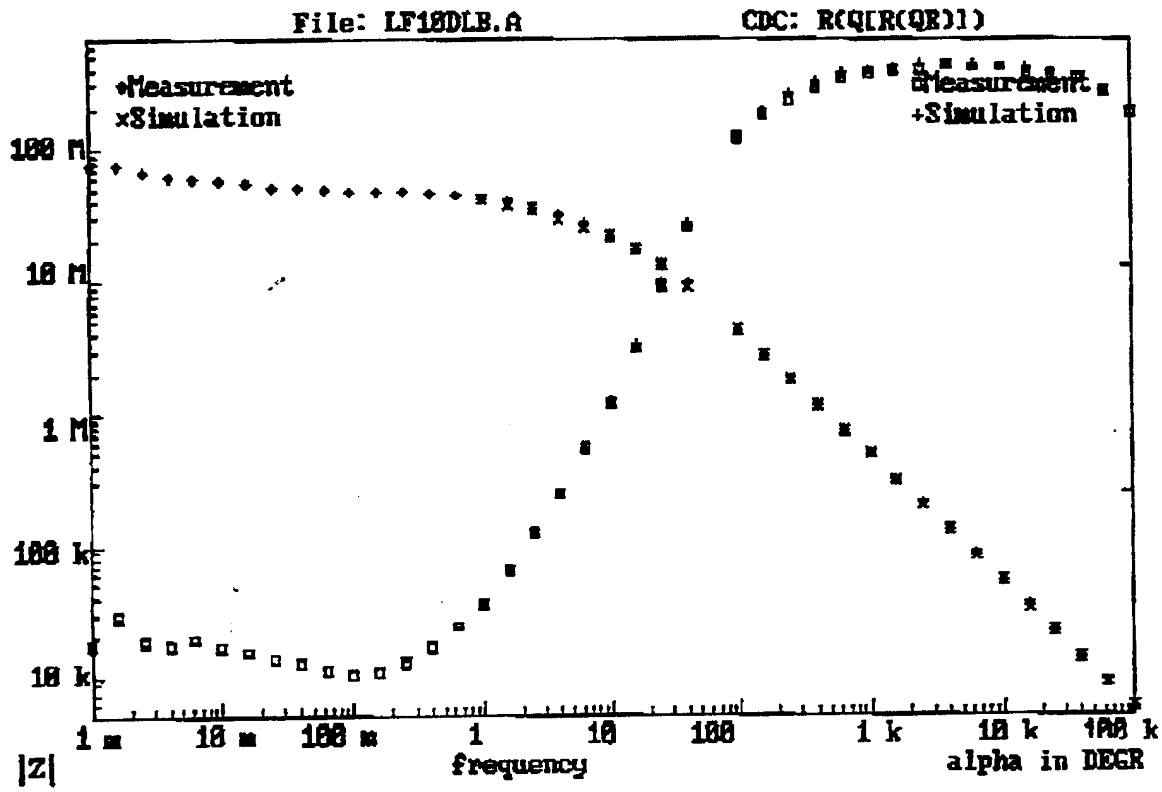

Figure 19: Fit of data from Table 20.

```
Pathname    : b:\
Filename    : 15R10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388       2.71
Ambient:  -700
Electrode:  7.5440E+00

Freq. range:  1.000E+00 -  1.000E+05 Herz
Data set   :    25 frequencies

CircuitCode: R(Q[R(QR)])

Chi-Squared:  1.24E-04

Resistance    - 1=  6.575E+02        8.06 %   [ohm]
C-P Elmnt, Yo- 2=  4.330E-10        1.32 % ["mho"]
Freq power, n- 2=  0.9674           0.13 %
Resistance    - 3=  2.391E+07        4.13 %   [ohm]
C-P Elmnt, Yo- 4=  4.346E-09        9.80 % ["mho"]
Freq power, n- 4=  0.7032           5.99 %
Resistance    - 5=  2.991E+07        7.34 %   [ohm]
```

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5
R- 1:	1.00						
Q- 2:	-0.36	1.00					
n- 2:	0.38	-0.98	1.00				
R- 3:	-0.24	0.70	-0.66	1.00			
Q- 4:	0.03	-0.12	0.10	-0.42	1.00		
n- 4:	-0.15	0.45	-0.41	0.84	-0.83	1.00	
R- 5:	-0.18	0.53	-0.49	0.85	-0.77	0.95	1.00

Table 21: Computer printout of fit of 2 time constant model to data obtained at -700 mV (REF). See Figure 20 for plot illustrating fit.

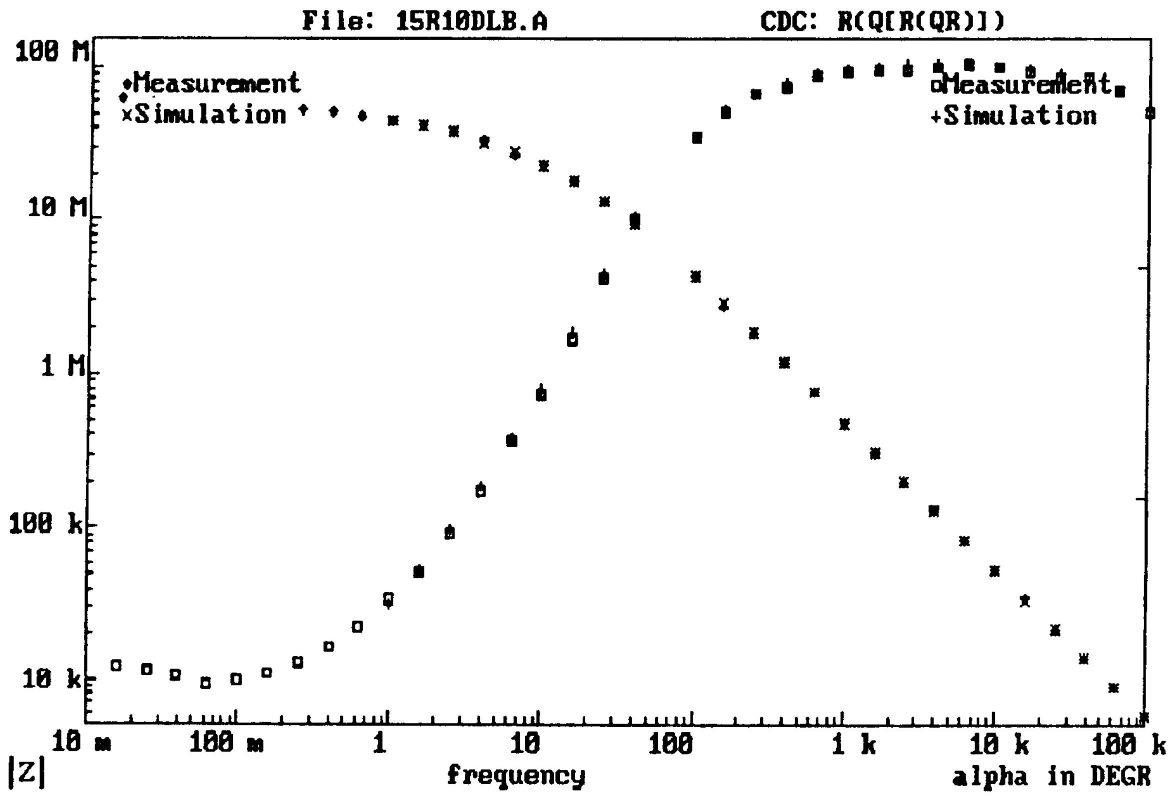

Figure 20: Fit of data from Table 21.

```
Pathname    : b:\
Filename    : 20R10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388       2.71
Ambient:  -500
Electrode:  7.5440E+00

Freq. range:  1.000E+00 -  1.000E+05 Herz
Data set    :    25 frequencies

CircuitCode: R(Q[R(QR)])

Chi-Squared:  1.29E-04

Resistance     - 1=  6.466E+02      8.29 %   [ohm]
C-P Elmnt, Yo- 2=  4.368E-10      1.25 % ["mho"]
Freq power, n- 2=  0.9667         0.13 %
Resistance     - 3=  2.638E+07      3.11 %   [ohm]
C-P Elmnt, Yo- 4=  2.779E-09      5.77 % ["mho"]
Freq power, n- 4=  0.7419         2.92 %
Resistance     - 5=  1.650E+08      8.25 %   [ohm]
```

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5
R- 1:	1.00						
Q- 2:	-0.35	1.00					
n- 2:	0.36	-0.97	1.00				
R- 3:	-0.22	0.68	-0.64	1.00			
Q- 4:	0.11	-0.34	0.32	-0.67	1.00		
n- 4:	-0.14	0.43	-0.40	0.82	-0.96	1.00	
R- 5:	-0.11	0.36	-0.33	0.64	-0.93	0.90	1.00

Table 23: Computer printout of fit of 2 time constant model to data obtained at -500 mV (REF). See Figure 22 for plot illustrating fit.

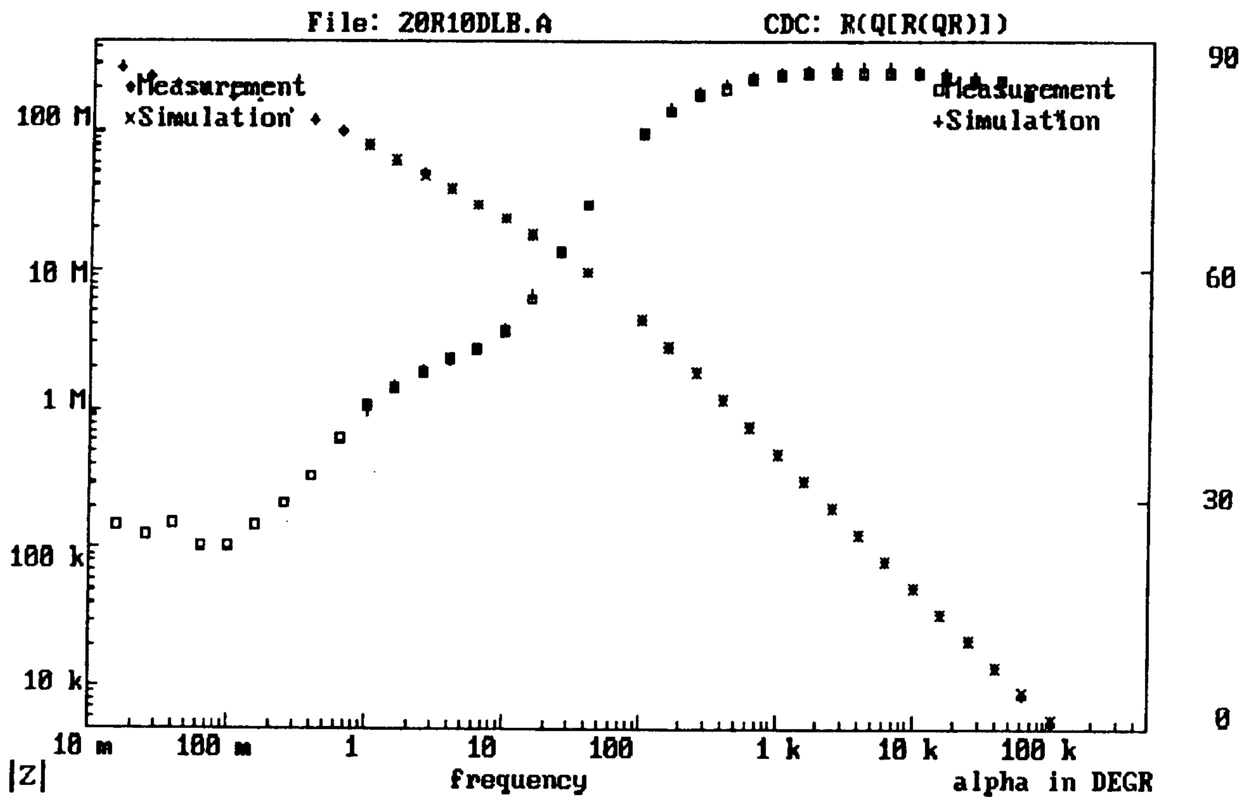

Figure 22: Fit of data from Table 23.

Pathname : b:\
Filename : RLF10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388 2.71
Ambient: -500
Electrode: 7.5440E+00

Freq. range: 1.000E+00 - 1.000E+05 Herz
Data set : 25 frequencies

CircuitCode: R(Q[R(QR)])

Chi-Squared: 1.49E-04

Resistance	- 1=	6.400E+02	8.99 %	[ohm]
C-P Elmnt, Yo-	2=	4.381E-10	1.33 %	["mho"]
Freq power, n-	2=	0.9666	0.14 %	
Resistance	- 3=	2.707E+07	3.23 %	[ohm]
C-P Elmnt, Yo-	4=	2.635E-09	6.02 %	["mho"]
Freq power, n-	4=	0.7532	2.99 %	
Resistance	- 5=	1.848E+08	9.18 %	[ohm]

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5
R- 1:	1.00						
Q- 2:	-0.34	1.00					
n- 2:	0.36	-0.97	1.00				
R- 3:	-0.22	0.68	-0.63	1.00			
Q- 4:	0.11	-0.35	0.32	-0.68	1.00		
n- 4:	-0.13	0.43	-0.40	0.81	-0.96	1.00	
R- 5:	-0.11	0.35	-0.32	0.63	-0.93	0.90	1.00

Table 24: Computer printout of fit of 2 time constant model to data obtained at -500 mV (REF). See Figure 23 for plot illustrating fit.

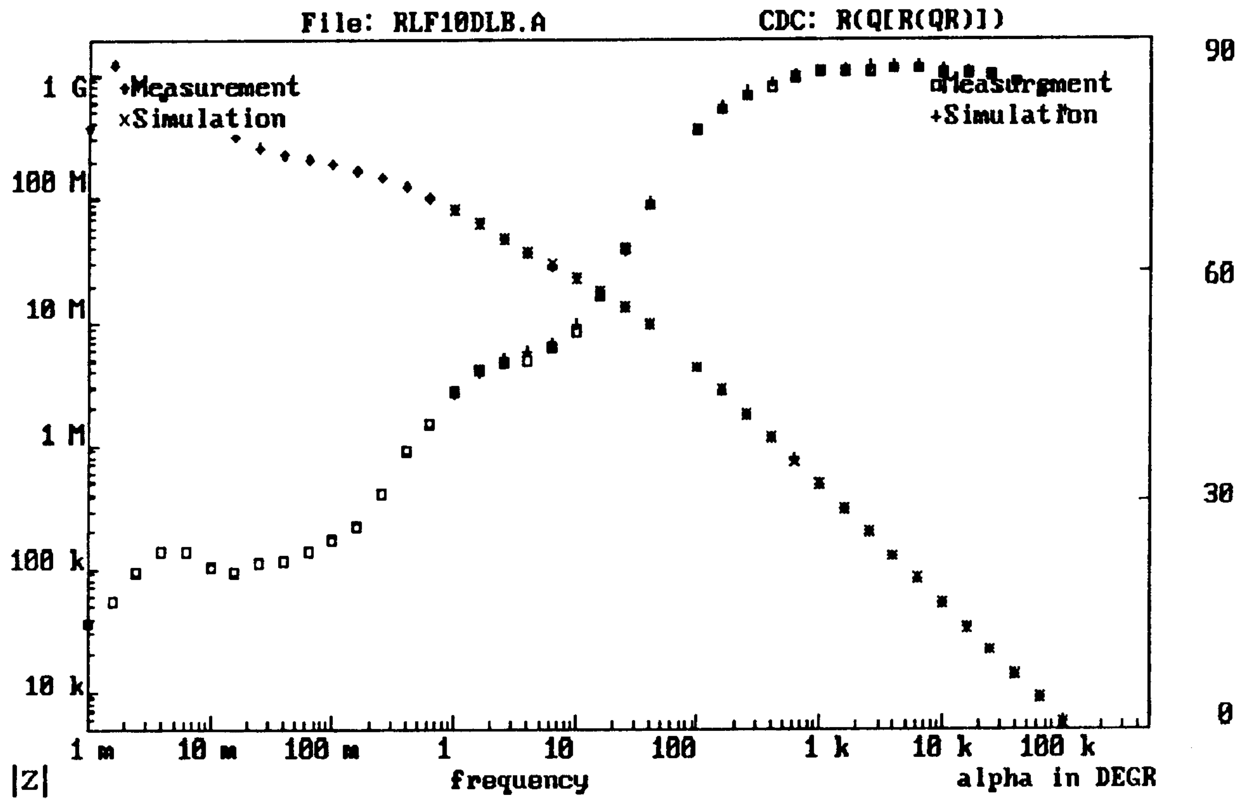

Figure 23: Fit of data from Table 24.

Pathname : b:\
Filename : 21R10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388 2.71
Ambient: -500
Electrode: 7.5440E+00

Freq. range: 1.000E+00 - 1.000E+05 Herz
Data set : 25 frequencies

CircuitCode: R(Q[R(QR)])

Chi-Squared: 1.61E-04

Resistance - 1=	6.352E+02	9.39 %	[ohm]
C-P Elmnt, Yo- 2=	4.331E-10	1.32 %	["mho"]
Freq power, n- 2=	0.9672	0.14 %	
Resistance - 3=	3.114E+07	2.96 %	[ohm]
C-P Elmnt, Yo- 4=	2.146E-09	5.77 %	["mho"]
Freq power, n- 4=	0.7992	2.73 %	
Resistance - 5=	2.396E+08	9.91 %	[ohm]

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5
R- 1:	1.00						
Q- 2:	-0.33	1.00					
n- 2:	0.35	-0.97	1.00				
R- 3:	-0.21	0.67	-0.62	1.00			
Q- 4:	0.11	-0.36	0.33	-0.67	1.00		
n- 4:	-0.13	0.42	-0.38	0.79	-0.96	1.00	
R- 5:	-0.10	0.33	-0.31	0.59	-0.91	0.89	1.00

Table 25: Computer printout of fit of 2 time constant model to data obtained at -500 mV (REF). See Figure 24 for plot illustrating fit.

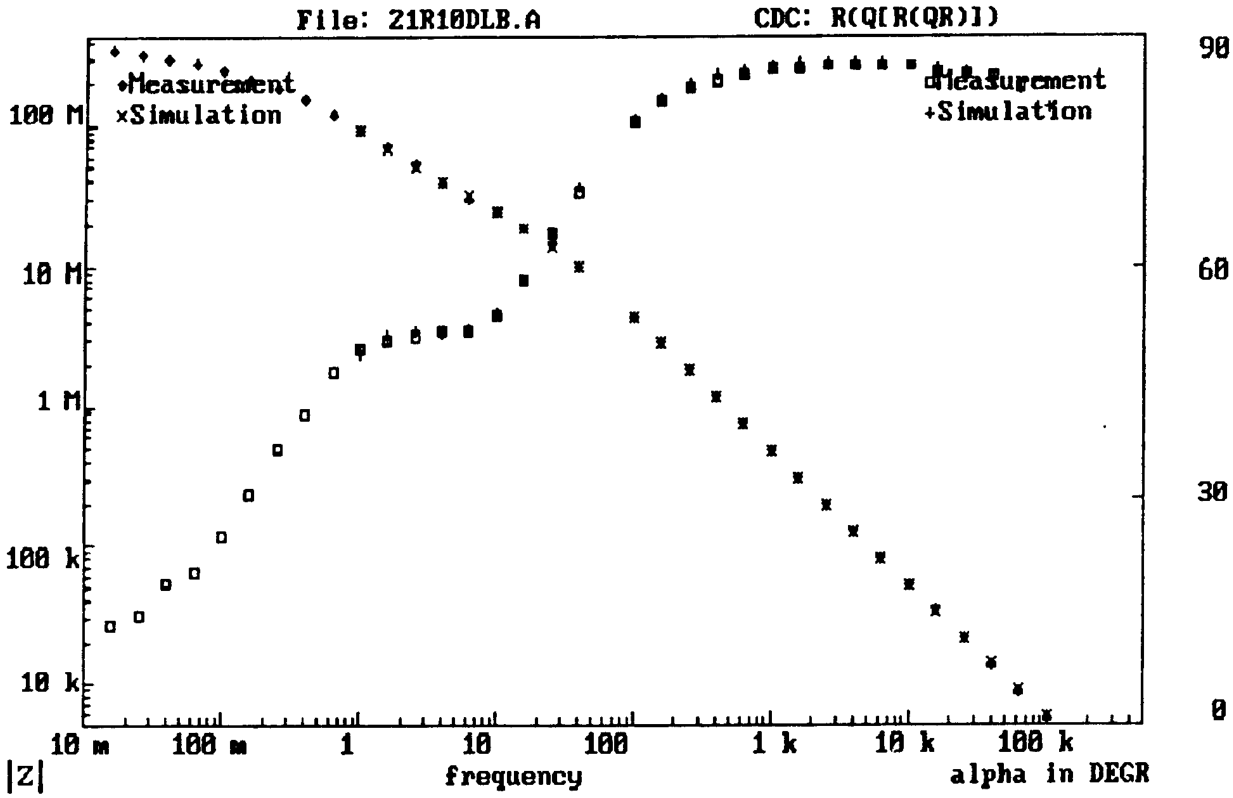

Figure 24: Fit of data from Table 25.

Pathname : b:\
Filename : 22R10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388 2.71
Ambient: -1000
Electrode: 7.5440E+00

Freq. range: 1.000E+00 - 1.000E+05 Herz
Data set : 25 frequencies

CircuitCode: R(Q[R(QR)])

Chi-Squared: 1.14E-04

Resistance	- 1=	6.614E+02	7.94 %	[ohm]
C-P Elmnt, Yo-	2=	4.237E-10	1.69 %	["mho"]
Freq power, n-	2=	0.9692	0.16 %	
Resistance	- 3=	2.321E+07	12.67 %	[ohm]
C-P Elmnt, Yo-	4=	1.404E-09	20.69 %	["mho"]
Freq power, n-	4=	0.7172	8.81 %	
Resistance	- 5=	1.933E+07	16.68 %	[ohm]

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5
R- 1:	1.00						
Q- 2:	-0.43	1.00					
n- 2:	0.45	-0.99	1.00				
R- 3:	-0.31	0.77	-0.73	1.00			
Q- 4:	-0.22	0.54	-0.52	0.50	1.00		
n- 4:	-0.14	0.39	-0.36	0.76	-0.16	1.00	
R- 5:	-0.30	0.74	-0.70	0.99	0.40	0.82	1.00

Table 26: Computer printout of fit of 2 time constant model to data obtained at -1000 mV (REF). See Figure 25 for plot illustrating fit.

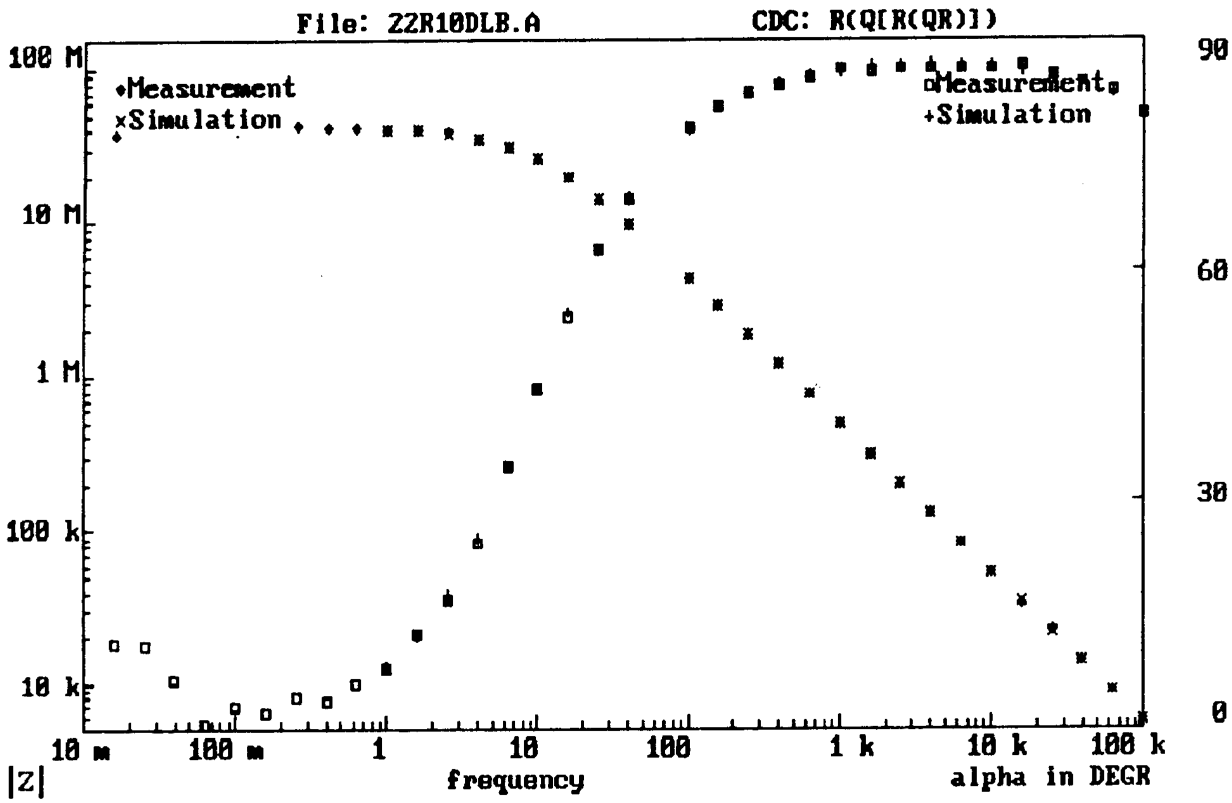

Figure 25: Fit of data from Table 26.

Pathname : b:\
Filename : 14R10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388 2.71
Ambient: -700
Electrode: 7.5440E+00

Freq. range: 1.585E-02 - 1.000E+05 Herz
Data set : 34 frequencies

CircuitCode: R(Q[R(QR)(QR)])

Chi-Squared: 1.04E-04

Resistance	- 1=	6.658E+02	7.25 %	[ohm]
C-P Elmnt, Yo-	2=	4.303E-10	1.17 %	["mho"]
Freq power, n-	2=	0.9680	0.12 %	
Resistance	- 3=	2.299E+07	3.22 %	[ohm]
C-P Elmnt, Yo-	4=	6.735E-07	30.80 %	["mho"]
Freq power, n-	4=	0.8934	13.51 %	
Resistance	- 5=	1.918E+07	32.33 %	[ohm]
C-P Elmnt, Yo-	6=	5.418E-09	6.93 %	["mho"]
Freq power, n-	6=	0.6952	4.68 %	
Resistance	- 7=	2.490E+07	5.73 %	[ohm]

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5	Q- 6	n- 6	R- 7
R- 1:	1.00									
Q- 2:	-0.36	1.00								
n- 2:	0.37	-0.98	1.00							
R- 3:	-0.22	0.68	-0.64	1.00						
Q- 4:	0.07	-0.23	0.21	-0.50	1.00					
n- 4:	0.06	-0.19	0.17	-0.42	0.96	1.00				
R- 5:	0.05	-0.15	0.14	-0.35	0.86	0.93	1.00			
Q- 6:	-0.02	0.05	-0.05	-0.22	0.72	0.63	0.53	1.00		
n- 6:	-0.13	0.42	-0.38	0.83	-0.74	-0.63	-0.53	-0.70	1.00	
R- 7:	-0.17	0.52	-0.49	0.88	-0.82	-0.73	-0.62	-0.59	0.94	1.00

Table 27: Computer printout of fit of 3 time constant model to data obtained at -700 mV (REF). See Figure 26 for plot illustrating fit.

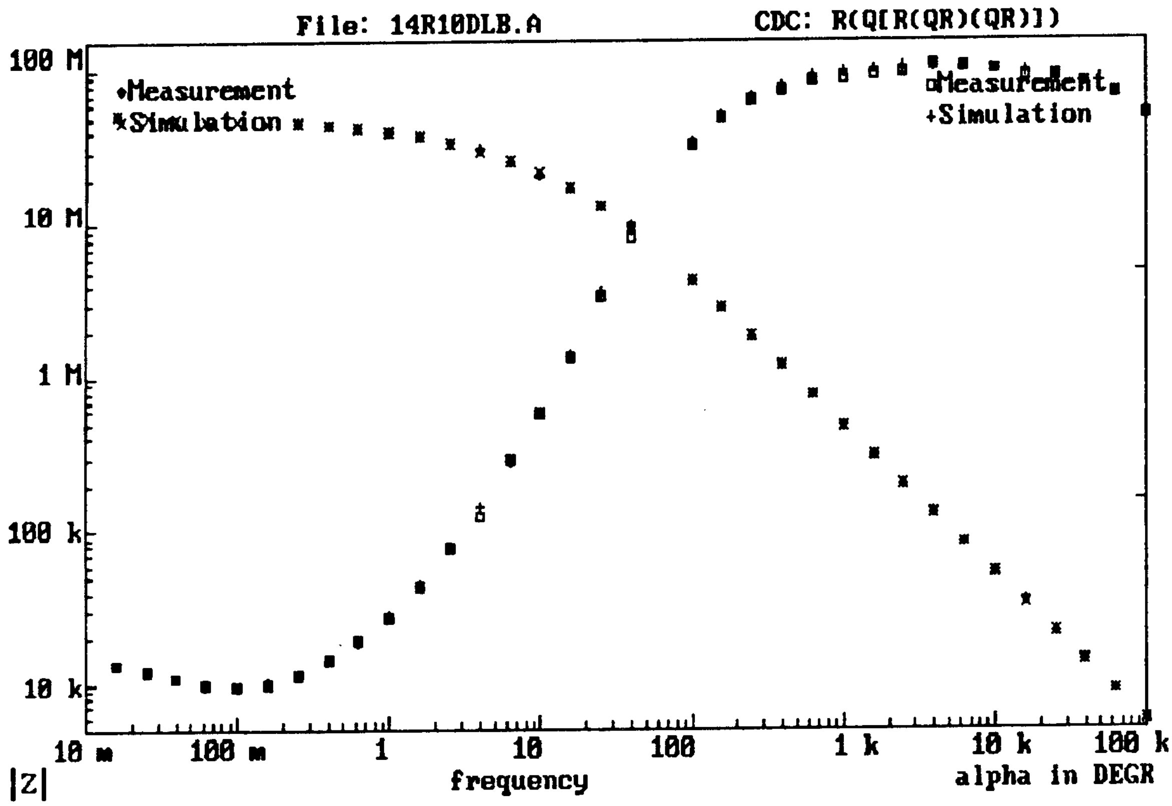

Figure 26: Fit of data from Table 27.

Pathname : b:\
Filename : LF10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388 2.71
Ambient: -700
Electrode: 7.5440E+00

Freq. range: 1.000E-03 - 1.000E+05 Herz
Data set : 40 frequencies

CircuitCode: R(Q[R(QR)(QR)])

Chi-Squared: 3.05E-04

Resistance - 1=	6.596E+02	12.54 %	[ohm]
C-P Elmnt, Yo- 2=	4.330E-10	1.96 %	["mho"]
Freq power, n- 2=	0.9673	0.20 %	
Resistance - 3=	2.336E+07	4.72 %	[ohm]
C-P Elmnt, Yo- 4=	3.080E-07	25.01 %	["mho"]
Freq power, n- 4=	0.5722	10.39 %	
Resistance - 5=	5.834E+07	17.10 %	[ohm]
C-P Elmnt, Yo- 6=	4.540E-09	10.44 %	["mho"]
Freq power, n- 6=	0.7459	6.67 %	
Resistance - 7=	2.335E+07	8.85 %	[ohm]

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5	Q- 6	n- 6	R- 7
R- 1:	1.00									
Q- 2:	-0.35	1.00								
n- 2:	0.37	-0.97	1.00							
R- 3:	-0.22	0.67	-0.63	1.00						
Q- 4:	0.06	-0.19	0.17	-0.41	1.00					
n- 4:	0.05	-0.16	0.14	-0.34	0.97	1.00				
R- 5:	0.04	-0.13	0.12	-0.28	0.86	0.93	1.00			
Q- 6:	-0.04	0.11	-0.11	-0.10	0.60	0.52	0.43	1.00		
n- 6:	-0.12	0.38	-0.35	0.79	-0.69	-0.60	-0.51	-0.65	1.00	
R- 7:	-0.16	0.50	-0.47	0.84	-0.81	-0.74	-0.63	-0.48	0.92	1.00

Table 22: Computer printout of fit of 3 time constant model to data obtained at -700 mV (REF). See Figure 21 for plot illustrating fit.

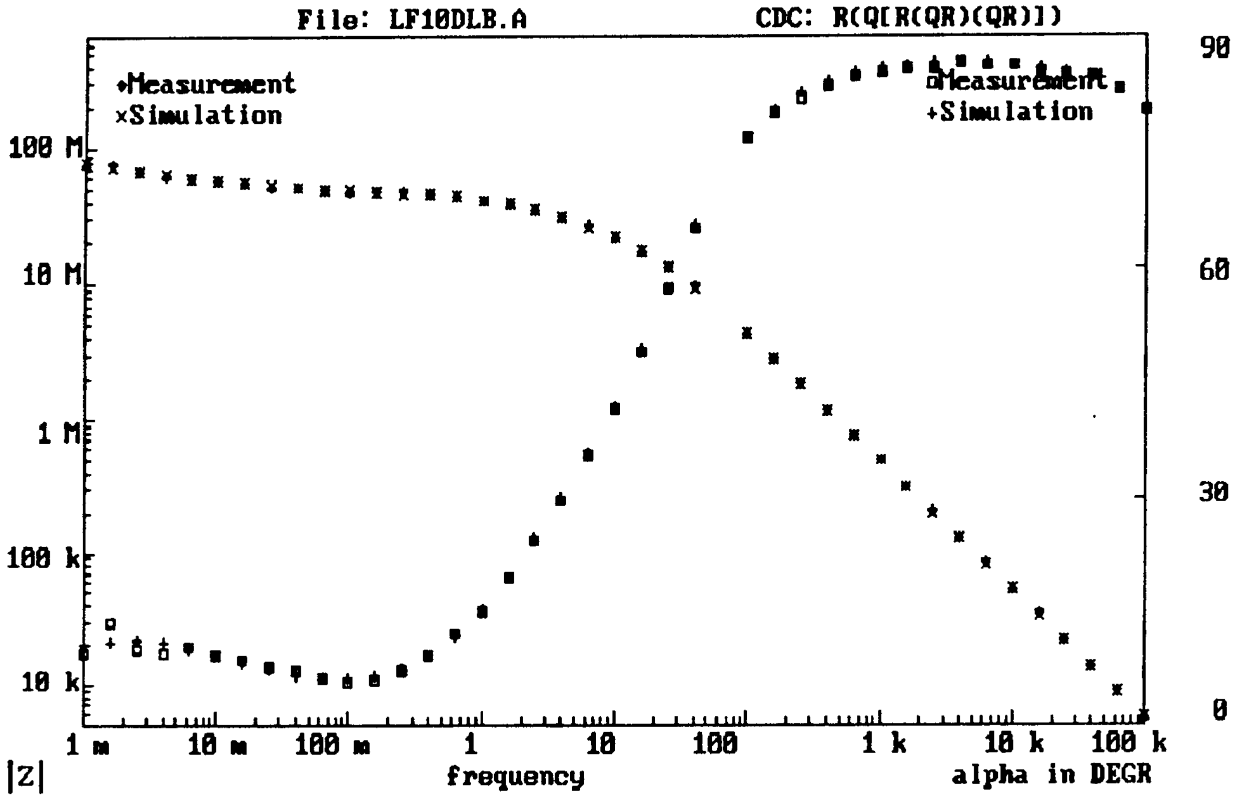

Figure 21: Fit of data from Table 22.

Pathname : b:\
Filename : 15R10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388 2.71
Ambient: -700
Electrode: 7.5440E+00

Freq. range: 1.585E-02 - 1.000E+05 Herz
Data set : 34 frequencies

CircuitCode: R(Q[R(QR)(QR)])

Chi-Squared: 1.74E-04

Resistance - 1=	6.671E+02	9.41 %	[ohm]
C-P Elmnt, Yo- 2=	4.298E-10	1.59 %	["mho"]
Freq power, n- 2=	0.9681	0.16 %	
Resistance - 3=	2.288E+07	5.37 %	[ohm]
C-P Elmnt, Yo- 4=	9.070E-07	48.35 %	["mho"]
Freq power, n- 4=	1.0000	17.19 %	
Resistance - 5=	1.272E+07	36.07 %	[ohm]
C-P Elmnt, Yo- 6=	5.067E-09	7.76 %	["mho"]
Freq power, n- 6=	0.6396	5.89 %	
Resistance - 7=	3.407E+07	6.78 %	[ohm]

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5	Q- 6	n- 6	R- 7
R- 1:	1.00									
Q- 2:	-0.37	1.00								
n- 2:	0.38	-0.98	1.00							
R- 3:	-0.24	0.70	-0.65	1.00						
Q- 4:	0.08	-0.23	0.21	-0.50	1.00					
n- 4:	0.06	-0.18	0.17	-0.41	0.96	1.00				
R- 5:	0.06	-0.18	0.16	-0.39	0.89	0.94	1.00			
Q- 6:	-0.04	0.10	-0.10	-0.16	0.70	0.61	0.56	1.00		
n- 6:	-0.14	0.43	-0.40	0.84	-0.73	-0.61	-0.57	-0.64	1.00	
R- 7:	-0.18	0.55	-0.51	0.90	-0.79	-0.69	-0.63	-0.53	0.95	1.00

Table 29: Computer printout of fit of 3 time constant model to data obtained at -700 mV (REF). See Figure 29 for plot illustrating fit.

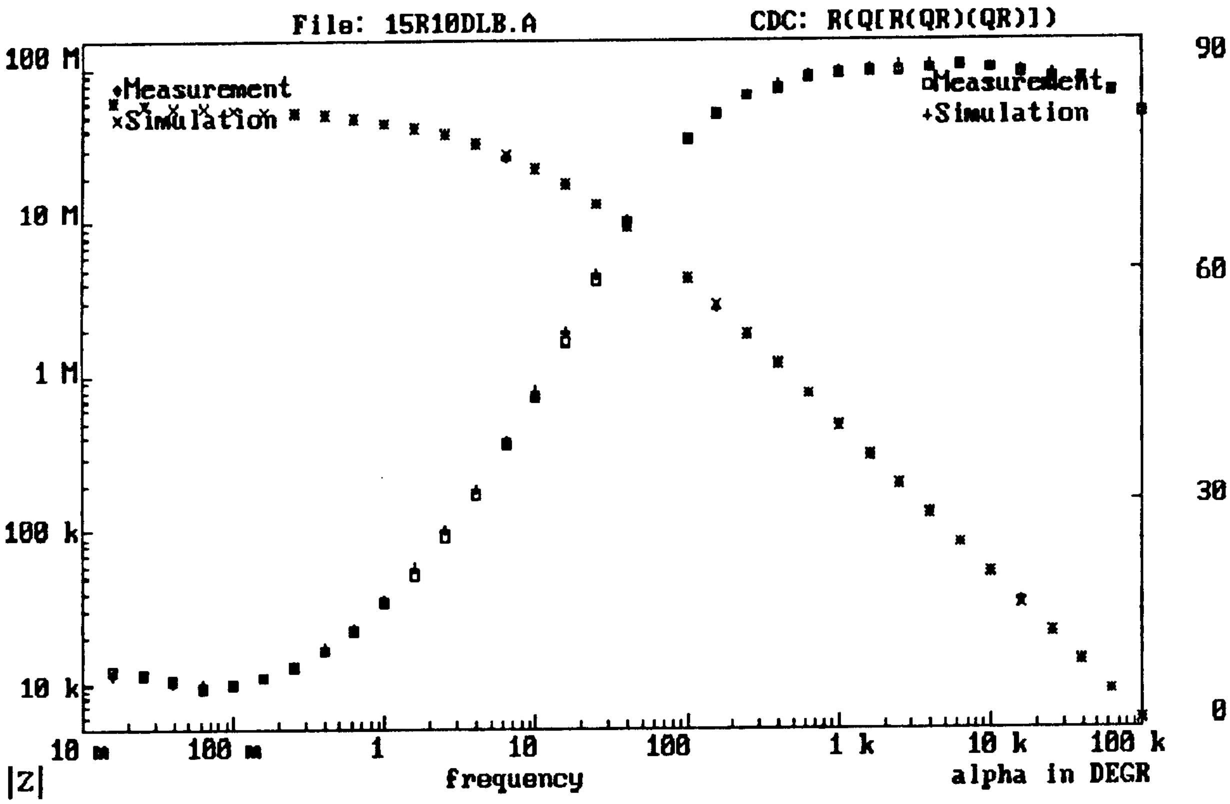

Figure 28: Fit of data from Table 29.

```
Pathname    : b:\
Filename    : 20R10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388        2.71
Ambient:  -500
Electrode:  7.5440E+00

Freq. range:  1.585E-02 -  1.000E+05 Herz
Data set   :     34 frequencies

CircuitCode: R(Q[R(QR)(QR)])

Chi-Squared:  2.41E-04

Resistance     - 1=  6.477E+02      11.26 %    [ohm]
C-P Elmnt, Yo- 2=  4.364E-10       1.63 % ["mho"]
Freq power, n- 2=  0.9668          0.17 %
Resistance     - 3=  2.656E+07      3.42 %    [ohm]
C-P Elmnt, Yo- 4=  3.077E-09       8.01 % ["mho"]
Freq power, n- 4=  0.7623          5.55 %
Resistance     - 5=  1.217E+08     23.86 %    [ohm]
C-P Elmnt, Yo- 6=  2.372E-08      41.89 % ["mho"]
Freq power, n- 6=  0.6484         24.38 %
Resistance     - 7=  7.055E+08     72.87 %    [ohm]
```

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5	Q- 6	n- 6	R- 7
R- 1:	1.00									
Q- 2:	-0.33	1.00								
n- 2:	0.35	-0.97	1.00							
R- 3:	-0.20	0.64	-0.60	1.00						
Q- 4:	0.02	-0.06	0.06	-0.35	1.00					
n- 4:	-0.05	0.16	-0.15	0.13	0.65	1.00				
R- 5:	-0.02	0.06	-0.06	-0.09	0.82	0.95	1.00			
Q- 6:	0.01	-0.03	0.03	0.16	-0.86	-0.93	-1.00	1.00		
n- 6:	0.00	-0.00	0.01	0.22	-0.91	-0.89	-0.98	0.99	1.00	
R- 7:	-0.00	0.02	-0.02	0.26	-0.91	-0.83	-0.92	0.94	0.98	1.00

Table 30: Computer printout of fit of 3 time constant model to data obtained at -500 mV (REF). See Figure 29 for plot illustrating fit.

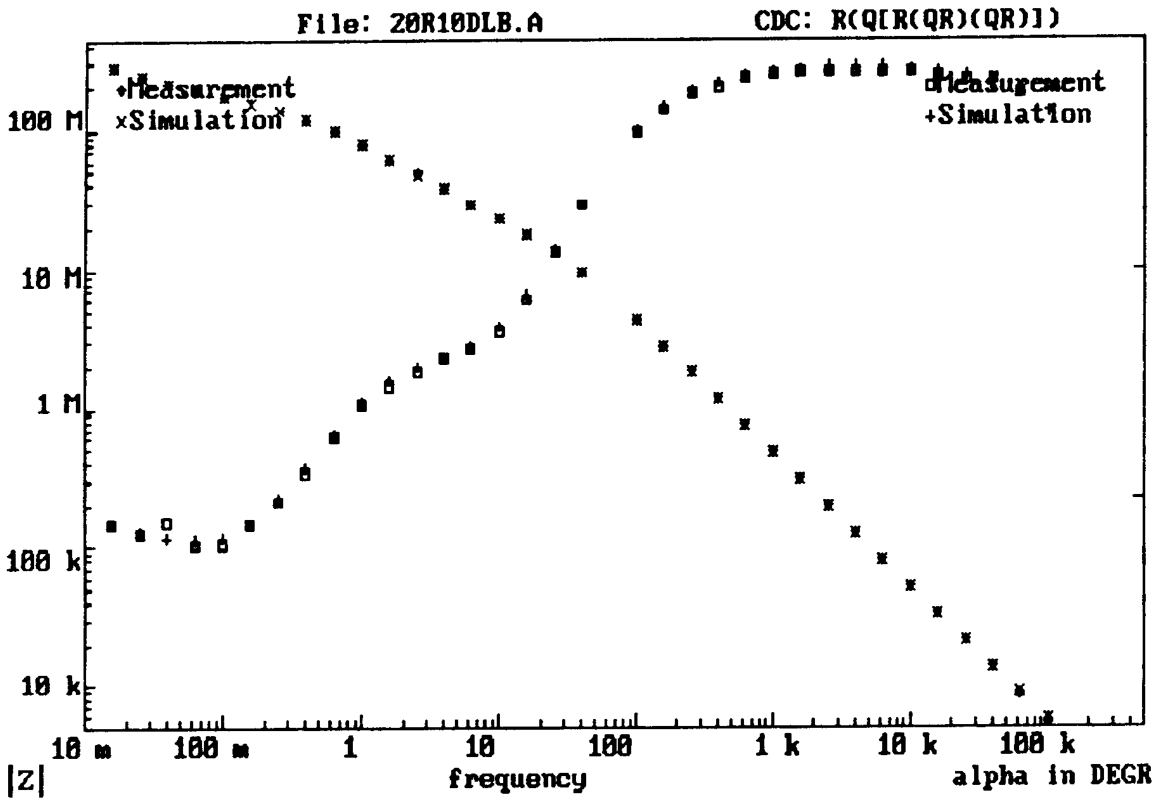

Figure 29: Fit of data from Table 30.

```
Pathname     : b:\
Filename     : 21R10DLB.A

Sample: 2024CC/E-COAT/SO2/BORATE
Date: 120294
Temp (C): M388        2.71
Ambient:  -500
Electrode:  7.5440E+00

Freq. range:  1.585E-02 -  1.000E+05 Herz
Data set    :    34 frequencies

CircuitCode: R(Q[R(QR)(QR)])

Chi-Squared:  1.92E-04

Resistance     - 1=  6.441E+02     10.10 %    [ohm]
C-P Elmnt, Yo- 2=  4.303E-10      1.41 % ["mho"]
Freq power, n- 2=  0.9678         0.15 %
Resistance     - 3=  3.026E+07      3.24 %    [ohm]
C-P Elmnt, Yo- 4=  2.525E-09     21.03 % ["mho"]
Freq power, n- 4=  0.7746         6.62 %
Resistance     - 5=  2.391E+08     42.56 %    [ohm]
C-P Elmnt, Yo- 6=  3.172E-08    210.77 % ["mho"]
Freq power, n- 6=  0.7021        63.50 %
Resistance     - 7=  1.717E+08    106.47 %    [ohm]
```

Correlation factors of NLLS-fit parameters:

Par.-#	R- 1	Q- 2	n- 2	R- 3	Q- 4	n- 4	R- 5	Q- 6	n- 6	R- 7
R- 1:	1.00									
Q- 2:	-0.33	1.00								
n- 2:	0.34	-0.97	1.00							
R- 3:	-0.19	0.62	-0.58	1.00						
Q- 4:	0.04	-0.14	0.13	-0.53	1.00					
n- 4:	0.01	-0.03	0.02	-0.32	0.94	1.00				
R- 5:	0.02	-0.08	0.07	-0.43	0.98	0.99	1.00			
Q- 6:	-0.03	0.10	-0.09	0.46	-0.99	-0.98	-1.00	1.00		
n- 6:	-0.04	0.13	-0.11	0.52	-1.00	-0.96	-0.98	0.99	1.00	
R- 7:	-0.03	0.12	-0.10	0.49	-0.99	-0.96	-0.98	0.99	1.00	1.00

Table 31: Computer printout of fit of 3 time constant model to data obtained at -500 mV (REF). See Figure 30 for plot illustrating fit.

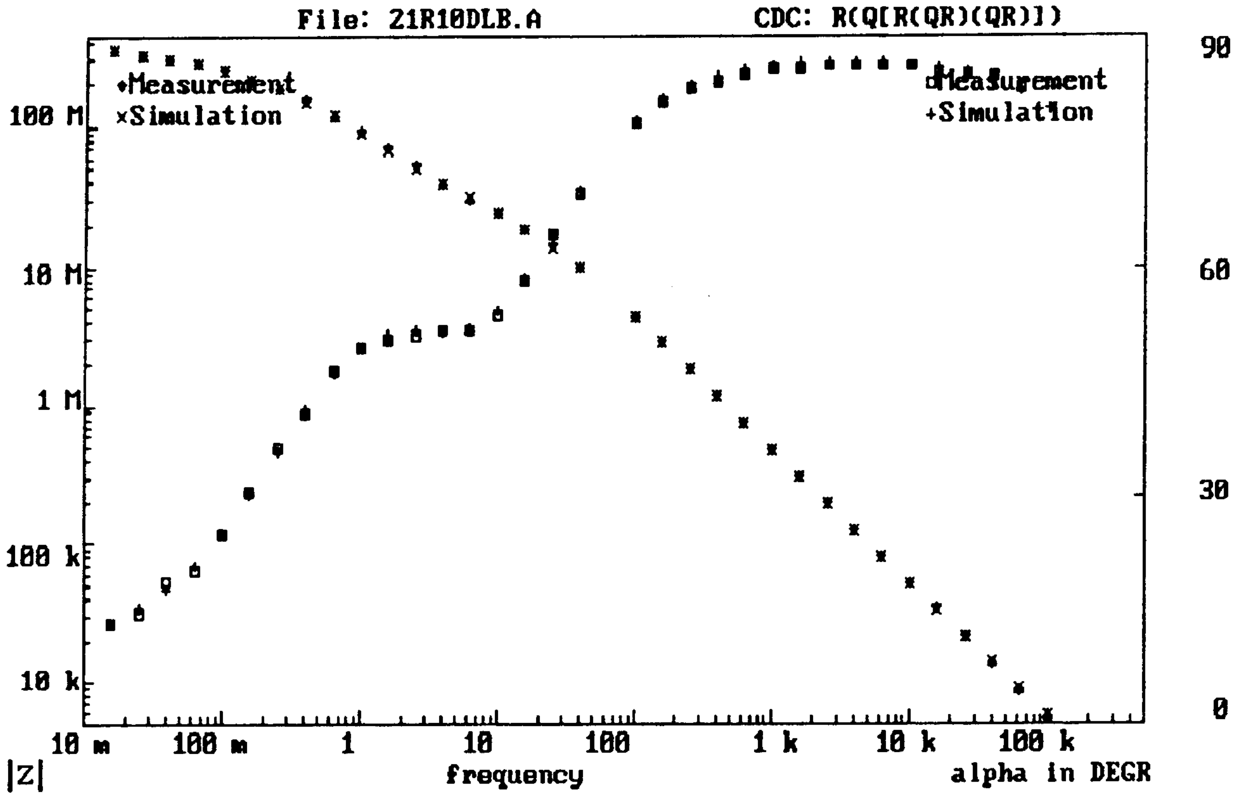

Figure 30: Fit of data from Table 31.

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ZERO DISCHARGE ORGANIC COATINGS

Powder Paint - UV Curable Paint - E-Coat

APPENDIX E

Table 41 - Absorbance VS. Wavelength Results

TABLE 41
Absorbance vs. Wavelength

Halox SZP-391, 0.11%,1 mm

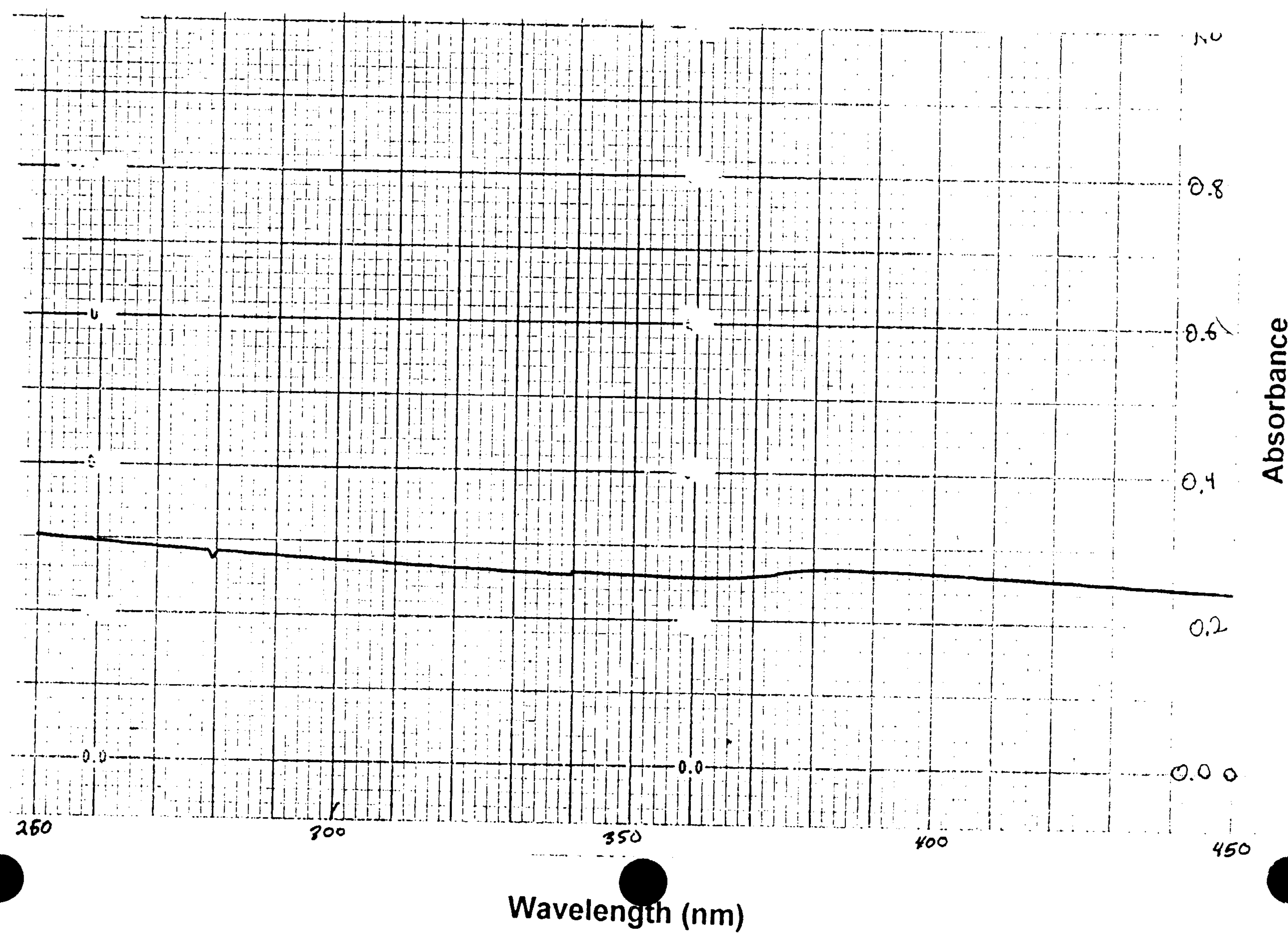


TABLE 41 – CONTINUED

Absorbance vs. Wavelength

Halox SZP-391, 0.31%, 1 mm

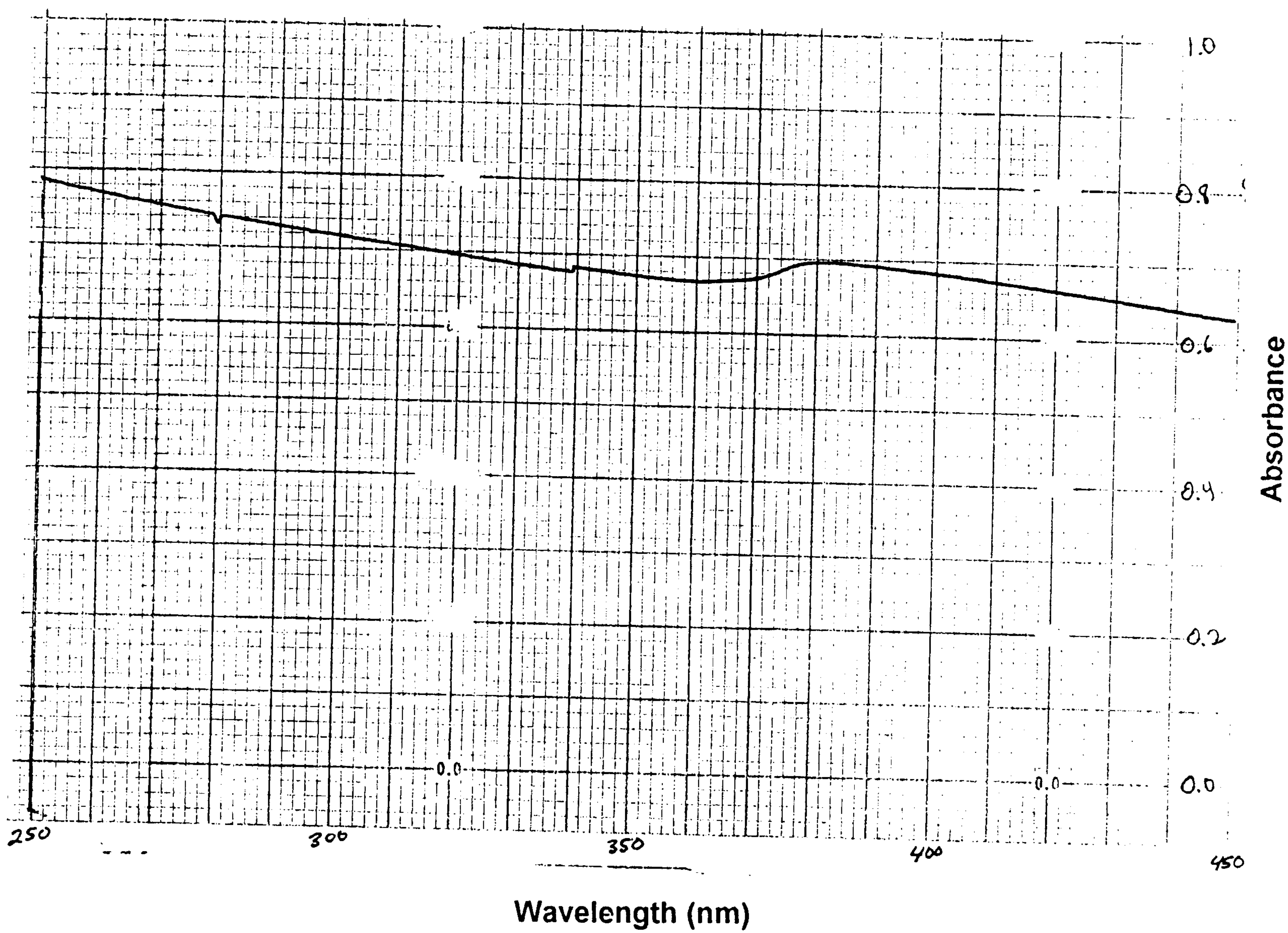


TABLE 41 - CONTINUED
Absorbance vs. Wavelength

J0866 Phosplus, 0.10%, 1 mm

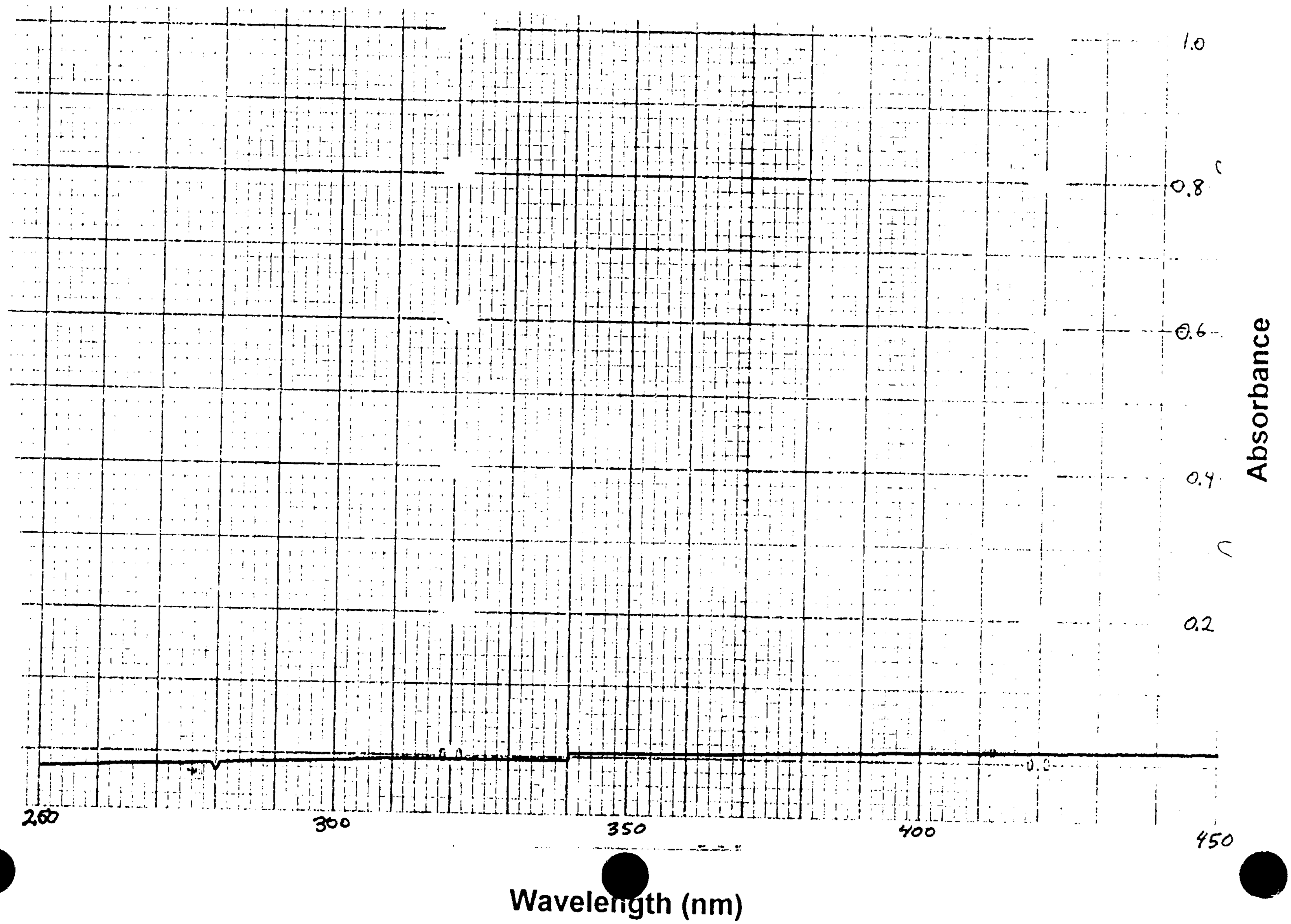


TABLE 41 – CONTINUED
Absorbance vs. Wavelength

KW-84 Itochou, 0.13%, 1 mm

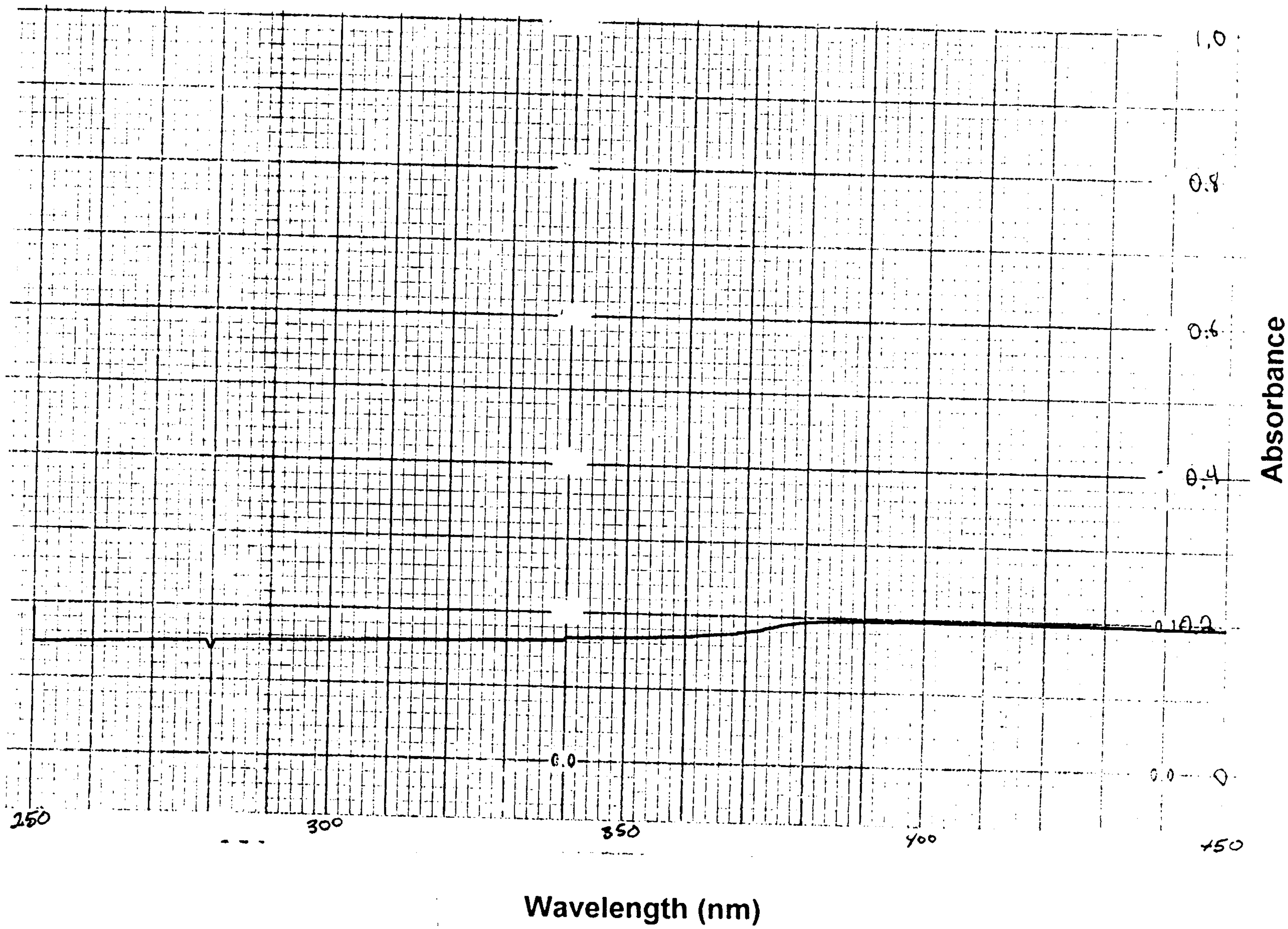


TABLE 41 - CONTINUED
Absorbance vs. Wavelength

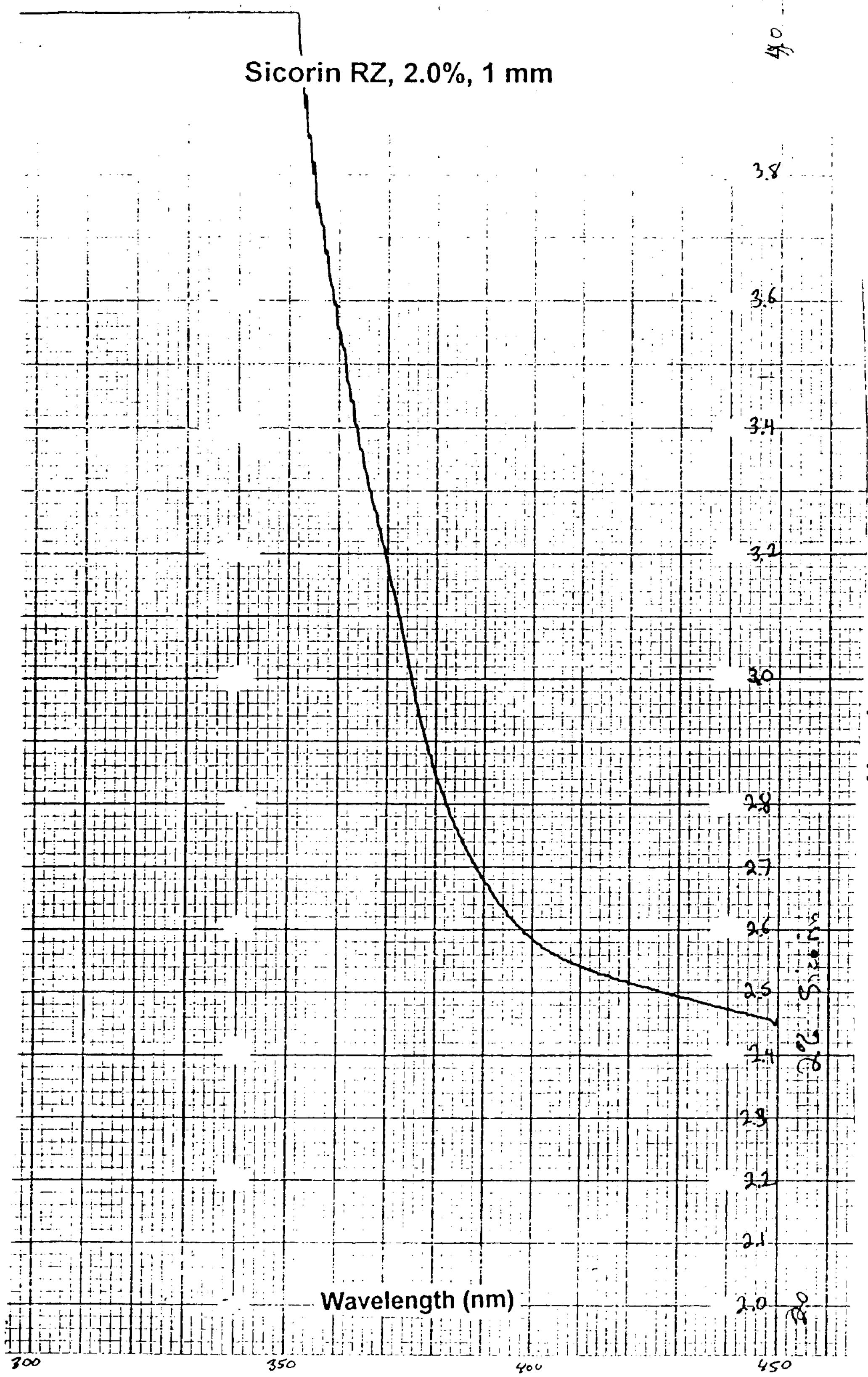


TABLE 41 — CONTINUED
Absorbance vs. Wavelength

Sicorin RZ, 0.20%, 1 mm

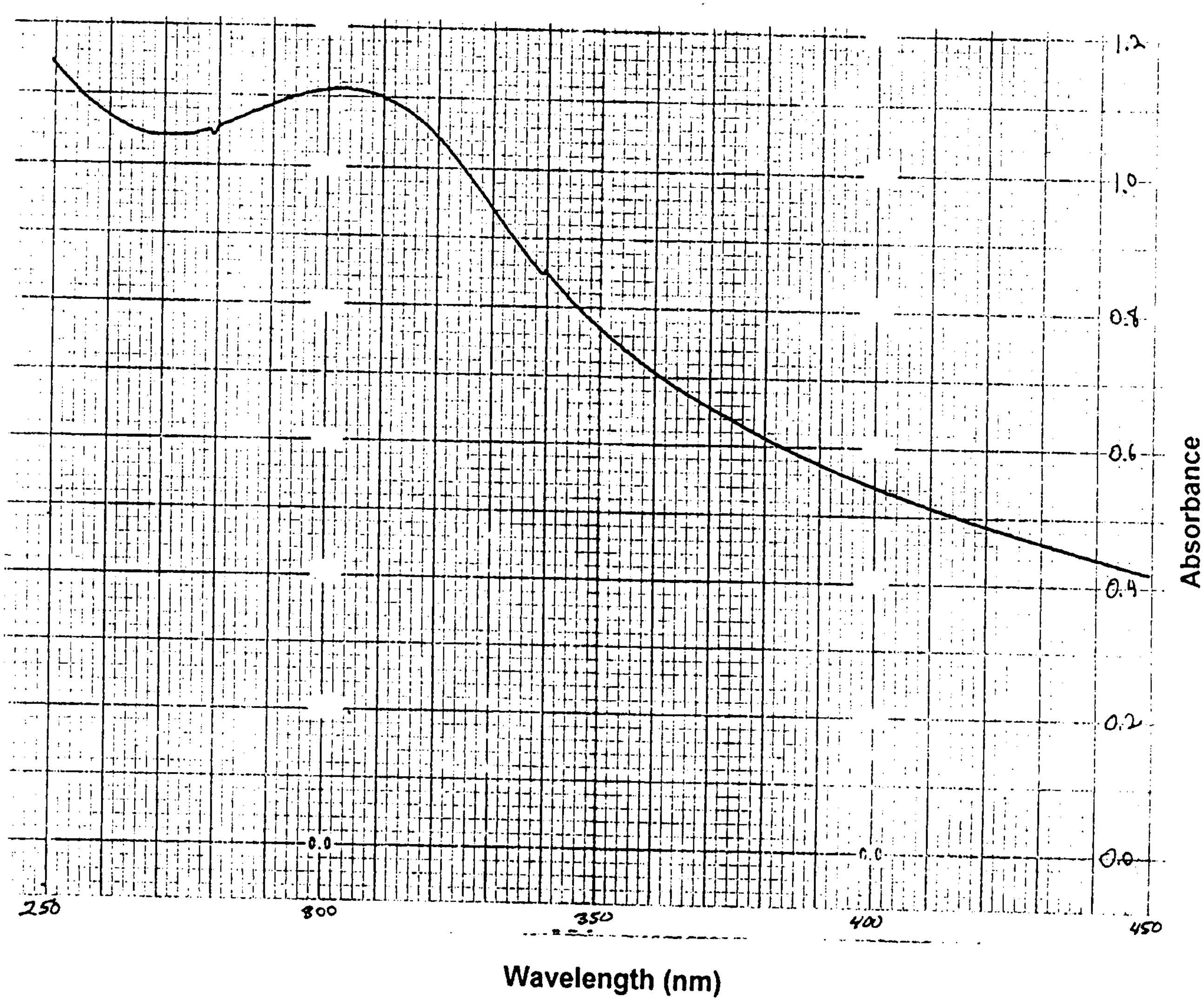


TABLE 41 - CONTINUED
Absorbance vs. Wavelength

Mixture:
J0866 Phosplus, 0.10%
Molywhite 101, 0.10%
Sicorin RZ, 0.10%

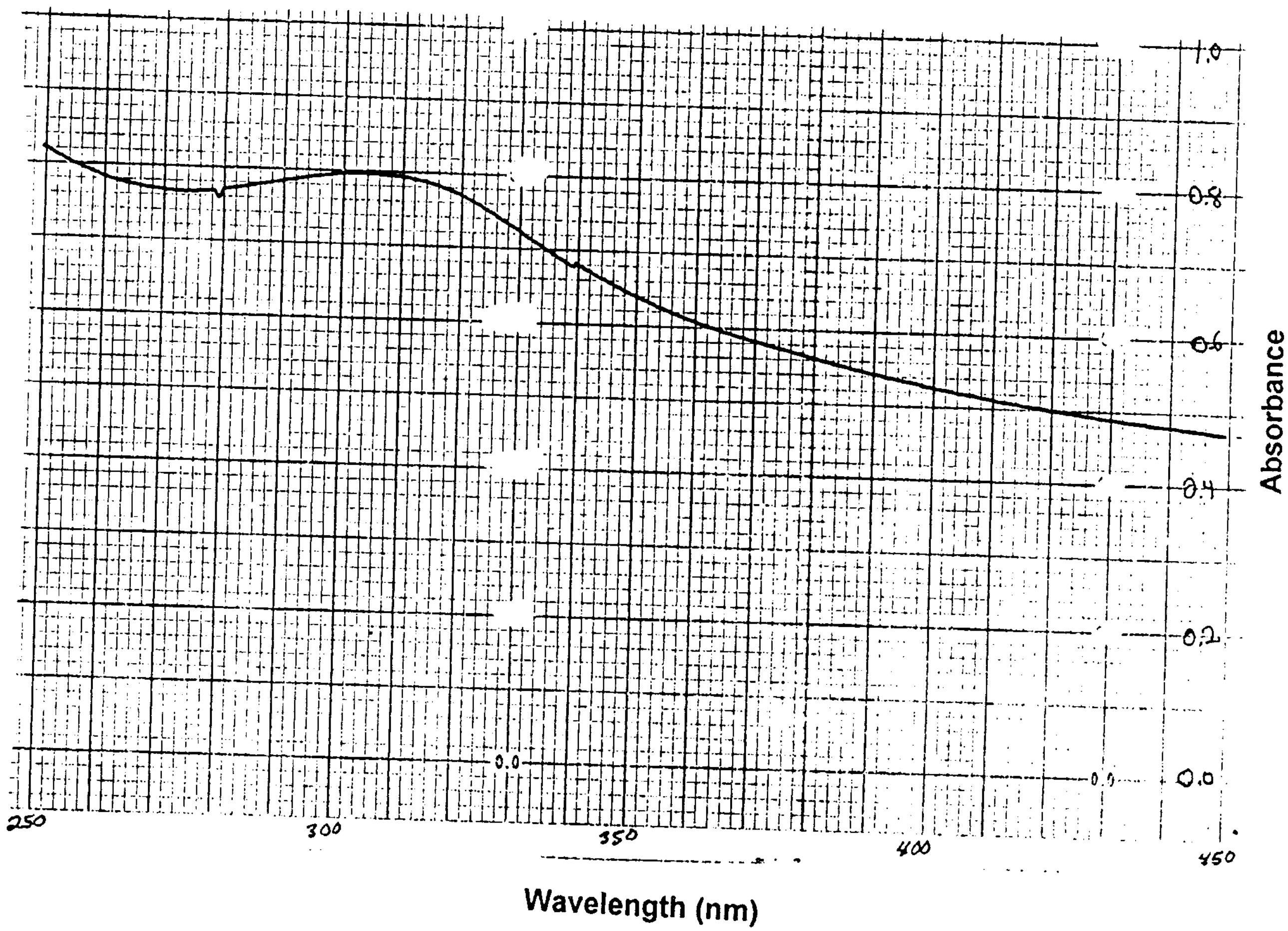


TABLE 41 - CONTINUED
Absorbance vs. Wavelength

KW-84 Itochou, 2.0%, 1 mm

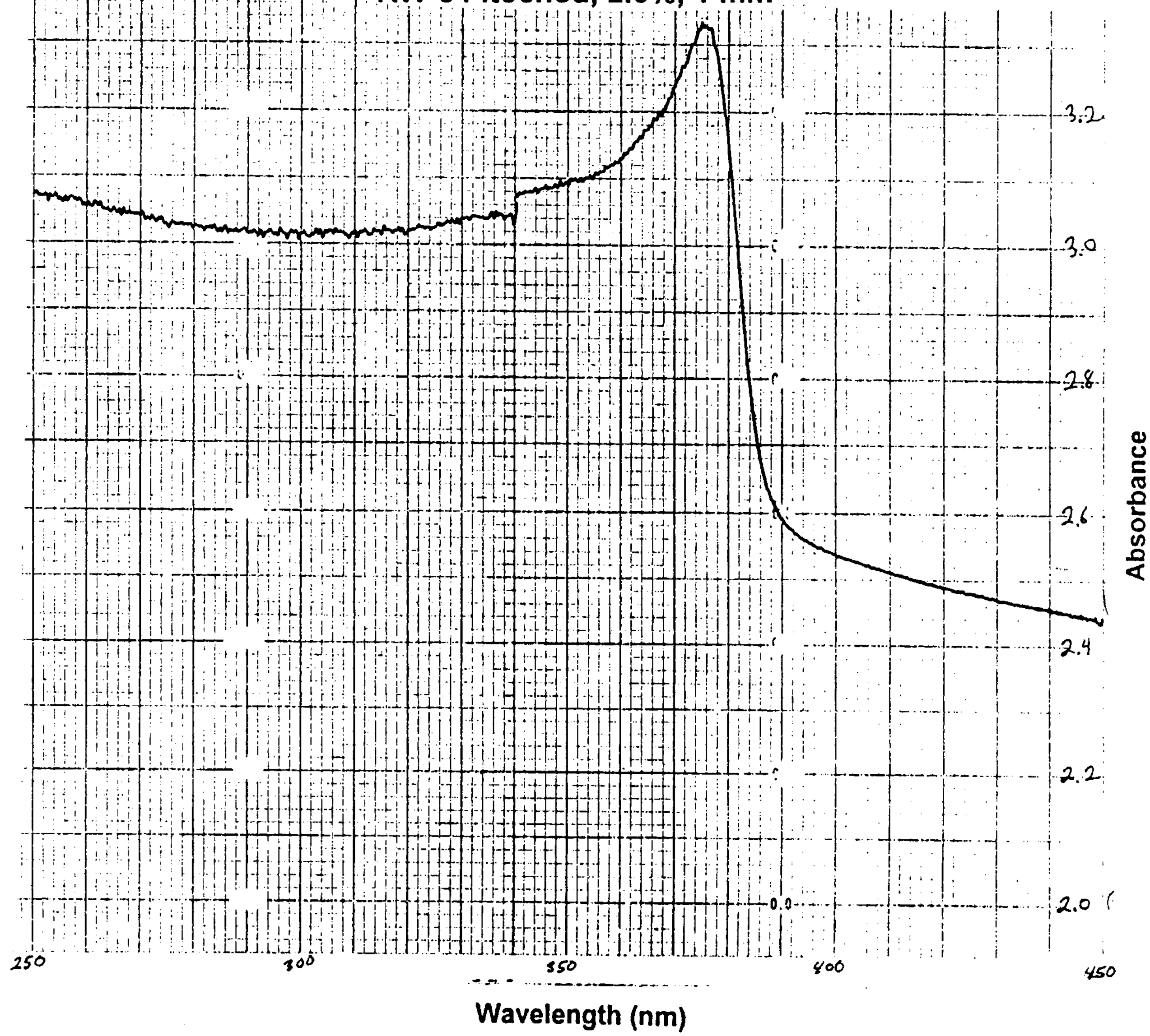


TABLE 41 - CONTINUED
Absorbance vs. Wavelength

Molywhite 101, 0.14%, 1 mm

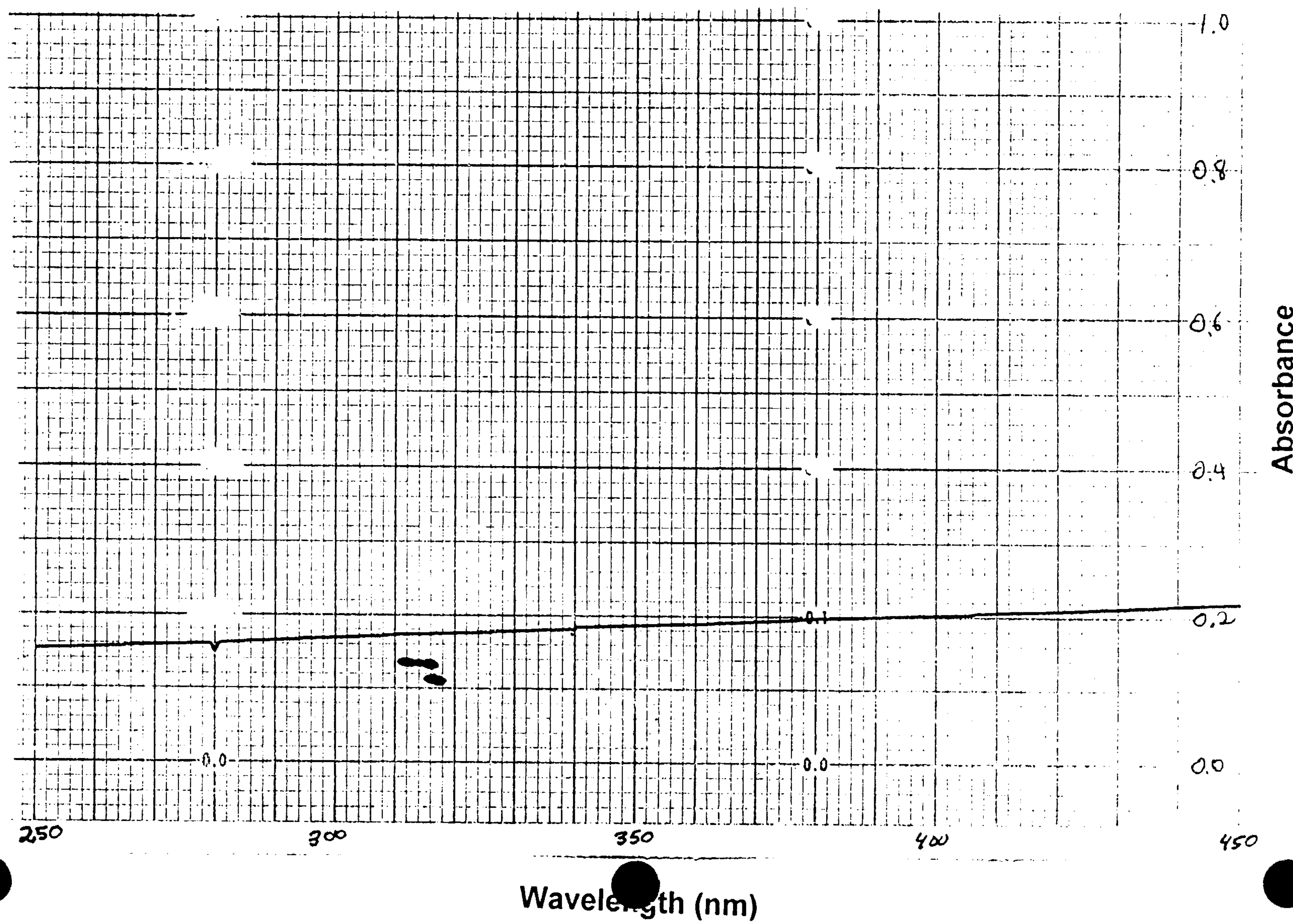


TABLE 41 - CONTINUED
Absorbance vs. Wavelength

Sicorin RZ, 0.10%, 1 mm

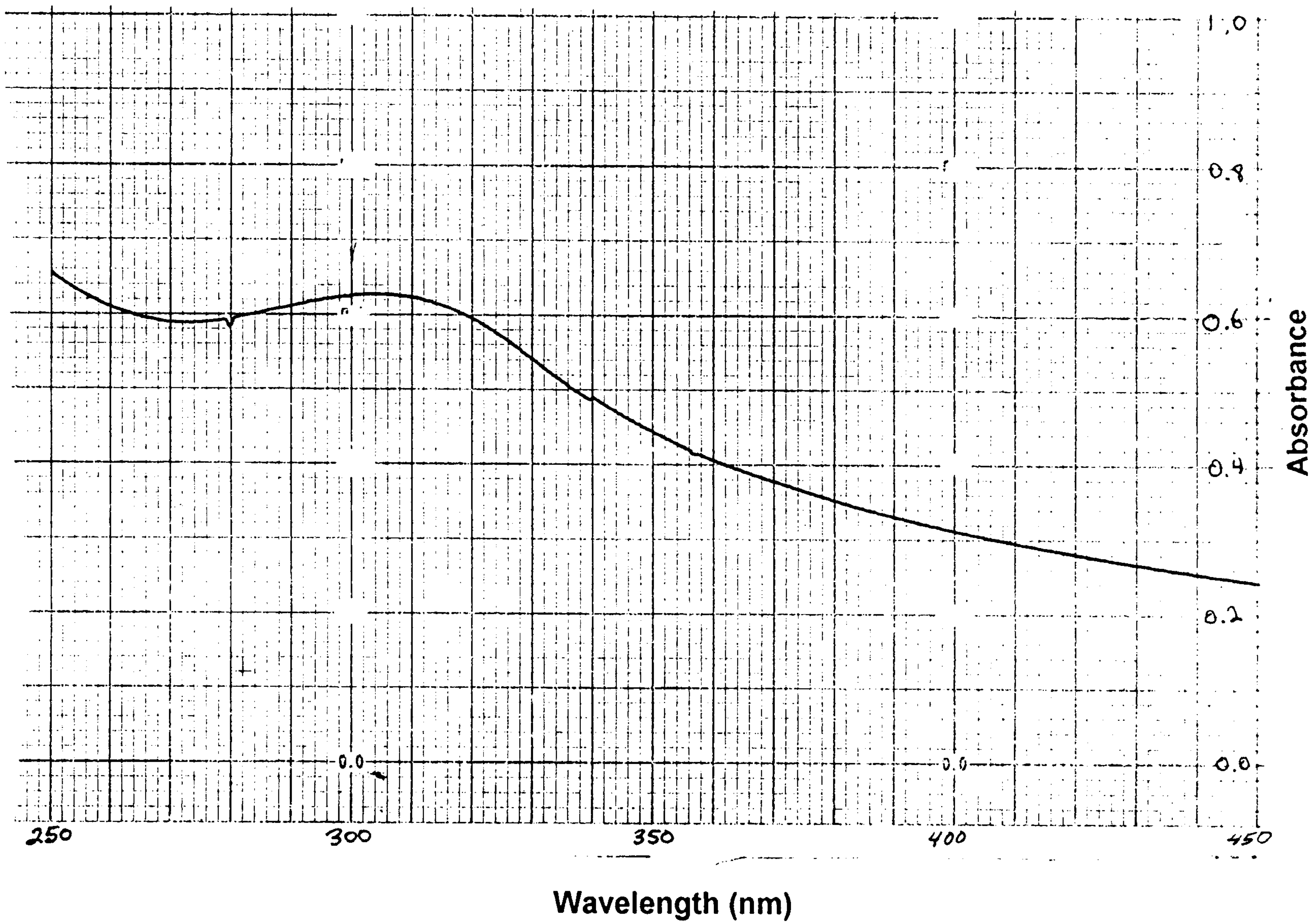
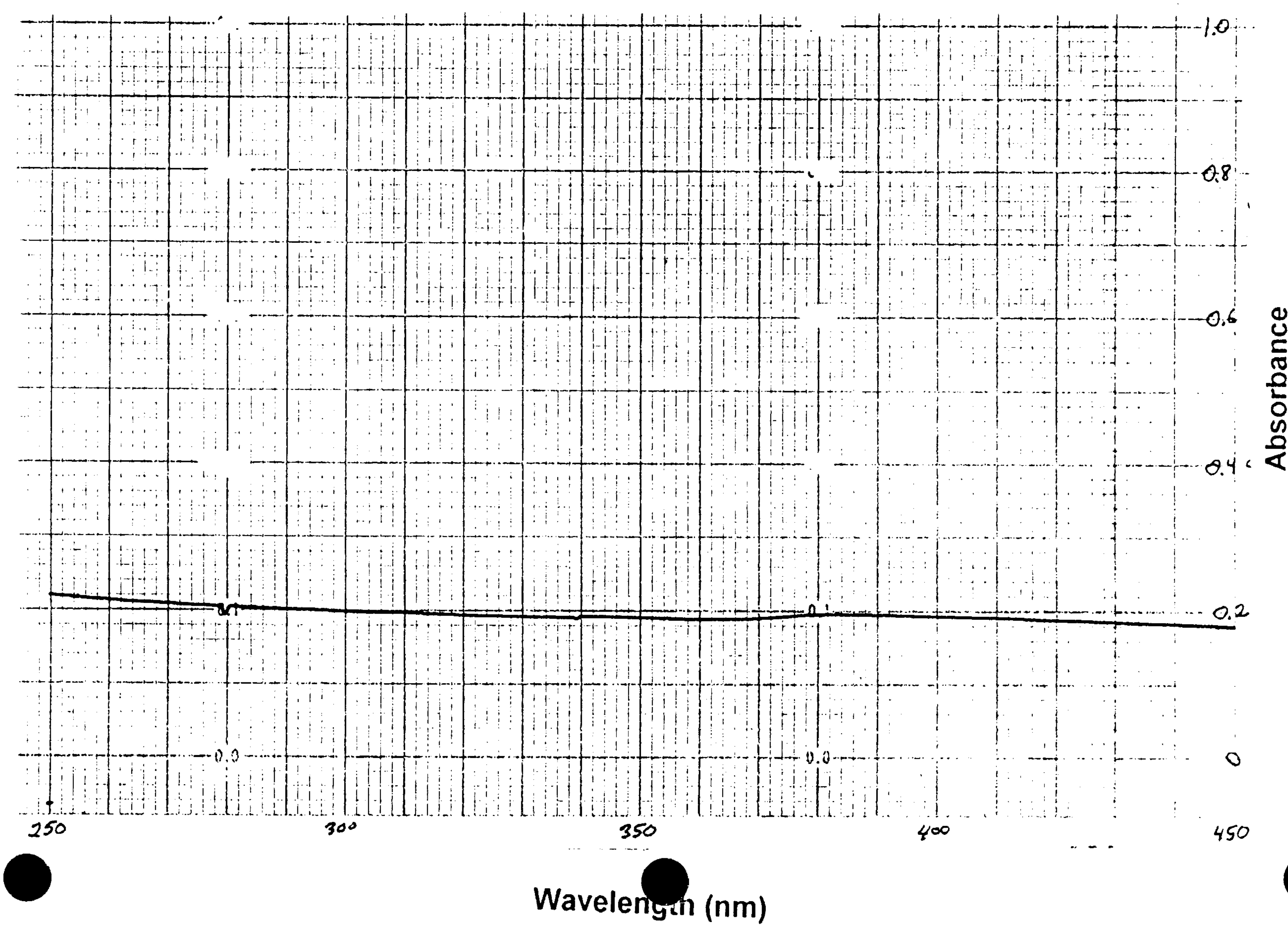


TABLE 41 - CONTINUED
Absorbance vs. Wavelength
Zinc Phosphate ZMP, 0.10%, 1 mm



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ZERO DISCHARGE ORGANIC COATINGS

Powder Paint - UV Curable Paint - E-Coat

APPENDIX F

Test Descriptions and Rating Systems for the Powder Coatings Development

Test Descriptions and Rating Systems for the Powder Coatings Development

MATERIALS

All of the tests on aluminum substrates in this effort were performed on 2024-T3 with a chromate conversion treatment conforming to MIL-C-81706 and MIL-C-5541, with two exceptions. The first exception was 2024 T3 Alclad with a chromate conversion treatment conforming to MIL-C-81706 and MIL-C-5541 which was used solely for the filiform test. The second exception was 2024-T0 with a chromic acid anodized treatment conforming to MIL-A-8625 which was used exclusively for G.E. impact and low temperature mandrel bend flexibility testing. All of the tests on steel substrates were conducted on both bare and zinc phosphated steel (SAE 1010, cold rolled, low carbon, ground on one side). The ground side was used as the test surface. The substrates designated as bare received no pretreatment. The substrates designated as zinc phosphated received a treatment according to DOD-P-16232, Type Z, Class III.

The control Navy coating system (often called the standard primer/topcoat system) consisted of a waterborne epoxy primer (MIL-P-85582) and a polyurethane topcoat (MIL-C-85285). The epoxy primer was applied at a dry film thickness of 15.2 to 22.9 microns (0.0006 to 0.0009 inches). The polyurethane topcoat was applied at a dry film thickness of 43.2 to 58.4 microns (0.0017 to 0.0023 inches). The target dry film thickness of the candidate powder coatings was 43.2 to 58.4 microns (0.0017 to 0.0023 inches).

The powder coatings were based on epoxy, acrylic, and epoxy-phenolic hybrid polymeric resin systems. The powder coatings were cured in a conventional convection oven for a period of 30 minutes at temperatures ranging from 121°C (250°F) to 149°C (300°F) depending on resin chemistry. The standard primer/topcoat was cured for a period of 14 days at ambient laboratory conditions (approximately 25°C, 50% relative humidity).

ADHESION

Adhesion to the test substrates was evaluated using both dry and wet tape adhesion tests. The tape test procedure used in this effort is a modified version of the ASTM D 3359, method A. For the dry tape test, two parallel scribes, 1.9 cm (0.75 in) apart, were cut through the coating and into the substrate. An "X" was subsequently scribed through the coating between the two initial scribes. A strip of 3M Co #250 masking tape was then applied firmly to the coating surface parallel to the scribe lines and

immediately removed with one quick motion. The tape is 2.54 cm (1 in) wide and at least a 5.1 cm (2 in) length of this tape should be used. The specimens were examined for removal and uplifting of the coating from the substrate and the adhesion was rated according to ASTM D 3359, method A rating system as listed below:

Rating - Description

5A - No peeling or removal

4A - Trace peeling or removal along incisions

3A - Jagged removal along incisions up to 1.6 mm (0.0625 in) one either side

2A - Jagged removal along most of incisions up to 3.2 mm (0.125 in) on either side

1A - Removal from most of the area of the X under the tape

0A - Removal beyond the area of the X

The wet tape test was performed by immersing specimen in distilled water at specified durations and temperatures. Three immersion conditions were used for this test: 24 hours at room temperature or 25°C (77°F), 96 hours at 49°C (120°F), and 168 hours at 65°C (150°F). Immediately upon removal from water immersion, the specimen are gently dried with a lint-free cloth and tested per the dry tape test procedure.

WATER AND HUMIDITY RESISTANCE

The water resistance of the coating systems was characterized by examining the coating test surface for defects such as softening, uplifting, or blistering which may result from distilled water immersion exposure for 24 hours at room temperature or 25°C (77°F), 96 hours at 49°C (120°F), and 168 hours at 65°C (150°F). Humidity resistance per ASTM D 2247 was characterized by examining the coating test surface for defects such as softening, uplifting, or blistering which may result from exposure to 30 days in a humidity cabinet maintained at 49°C (120°F) and 100% relative humidity. Development of any coating defect on the coating surface was considered a failing rating for these tests.

ACCELERATED WEATHERING

Accelerated weathering per ASTM G26, Type BH was performed by exposing candidate coatings on 2 aluminum test substrate to a

xenon-arc weatherometer for 500 hr. The continuous exposure cycle consisted of 102 minutes of high intensity light (0.35 watts/m^2 @ 340 nm wavelength) followed by 18 minutes of light and water spray. The chamber conditions include a 140°F black body temperature and 50% relative humidity. Optical properties, such as color and gloss, and flexibility properties, such as G.E. Impact, are typically used to quantify the resistance properties of coatings to the photodegradative effects of this exposure chamber. Acceptable high performance coatings designed for exterior applications are expected to remain nearly unchanged after exposure to accelerated weathering.

CHEMICAL (FLUID) RESISTANCE

The ability of the coatings to resist common operational fluids used on aircraft was evaluated by immersing each coating system on aluminum under various exposure conditions. Specimen from each coating system were immersed for twenty four hours in lubricating oil conforming to MIL-L-23699 at 121°C (250°F) and hydraulic fluid conforming to MIL-H-83282 at 65°C (150°F). Specimen were also immersed in a hydrocarbon solvent (JP-5 aircraft jet fuel) at 25°C (77°F) for 7 days. Upon removal, the coatings were examined for softening, uplifting, blistering, and other defects which may have resulted from the immersion exposure. Resistance to the abrasive and chemical degradation of a cloth soaked with solvent (methyl ethyl ketone) was also tested. Resistance to 50 passes (or 25 double rubs) such that the substrate was not exposed was the criterion for passing.

STRIPPABILITY

Coatings for military aircraft are required to be removed or stripped at regular scheduled intervals (i.e., 4 - 8 years) for corrosion control purposes. To ensure that coating removal will not be a problem when this scheduled maintenance interval occurs, a strippability test is performed during the coating development stage. This property was quantified by applying a standard liquid chemical paint remover (MIL-R-81294) to the candidate coatings which are oriented 30° from vertical. After 1 hour, 90 to 100% removal is considered acceptable for the standard primer/topcoat system.

FLEXIBILITY

The impact flexibility of the coating systems was evaluated at 25°C (77°F) using FTMS Method 6226 (G.E. Impact). This test apparatus consisted of a solid steel cylinder weighing 1.69 kg (3.7 lbs) which has spherical knobs protruding from the end. These knobs were designed such that the coating system is subjected to 0.5, 1, 2, 5, 10, 20, 40, and 60% elongation. The impact was accomplished by allowing the steel cylinder to fall freely from a height of 1.05 meters (42 inches) through a hollow cylinder guide, striking the reverse side of the specimen. The imprints formed from the knobs were examined under 10X

magnification and recorded as the highest deformation without cracking of the coating. Flexibility was also evaluated at -51°C (-60°F) using ASTM D 522. The specimen were conditioned at this low temperature for 4 hours prior to testing. While in the low temperature environment, the specimen (coated surface away from mandrel) were tested by bending around a cylindrical mandrel in a single quick motion. The lowest mandrel diameter without cracking (under 10X magnification), peeling, or loss of adhesion is considered the low temperature mandrel flexibility test value.

CORROSION RESISTANCE

Six appropriate aluminum specimens for each coating system were scribed with a figure "X" through the coating into the substrate. Two specimens were exposed in 5% salt spray (ASTM B 117) for 2000 hours, two were exposed in SO_2/salt spray (ASTM G 85) for 500 hours, and two were exposed to the filiform test (ASTM D 2803) for 1000 hours. Four bare steel and four zinc phosphated steel specimen for each coating system were scribed with a single diagonal line (with a slope of +1). Two bare and two zinc phosphated steel substrates per coating system were exposed to 5% salt spray for 500 hours. The same type and number of steel substrates were exposed to SO_2/salt spray for 96 hours. Salt spray and SO_2/salt spray panels were placed in racks which produced an orientation of 15° from vertical. Filiform panels were placed in racks with vertical orientation. The panels were inspected for corrosion as listed below:

<u>Salt Fog and SO_2/Salt Fog on Aluminum</u>

Pass (P) = a slight amount of general surface corrosion permitted in scribe; no blistering, pitting or uplifting of coating

Borderline Pass (+) = moderate to heavy corrosion in scribe; no blistering, pitting or uplifting of coating

Borderline Failure (-) = moderate to heavy corrosion in scribe; initiation of blistering or pitting at scribe)

Failure (F) = significant pitting or blistering at scribe and/or & significant pitting or blistering away from scribe

Salt Fog and SO_2/Salt Fog on Steel

Pass (P) = creep rating of 9 - 10 per ASTM D 1654 and no defects away from scribe

Borderline Pass (+) = creep rating of 7 - 8 per ASTM D 1654 and no defects away from scribe

Borderline Failure (-) = creep rating of 5 - 6 per ASTM D 1654 and no defects away from scribe

Failure (F) = creep rating of 0 - 4 per ASTM D 1654 and/or defects away from scribe

Filiform

Pass (P) = no filaments greater than 6.4 mm (0.25 in) in length from the scribe and 51-100% of filaments less than 3.2 mm (0.125 in)

Borderline Pass (+) = no filaments greater than 6.4 mm (0.25 in) in length from the scribe and 40-50% of filaments less than 3.2 mm (0.125 in)

Borderline Failure (-) = one filament slightly greater than 6.4 mm (0.25 in) in length from the scribe and 40-50% of filaments less than 3.2 mm (0.125 in)

Failure (F) = one or more filaments significantly greater than 6.4 mm (0.25 in) in length from the scribe or 0-40% of filaments less than 3.2 mm (0.125 in)

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ZERO DISCHARGE ORGANIC COATINGS

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APPENDIX G

Impedance Spectra for the Inhibitor Characterization and Analysis

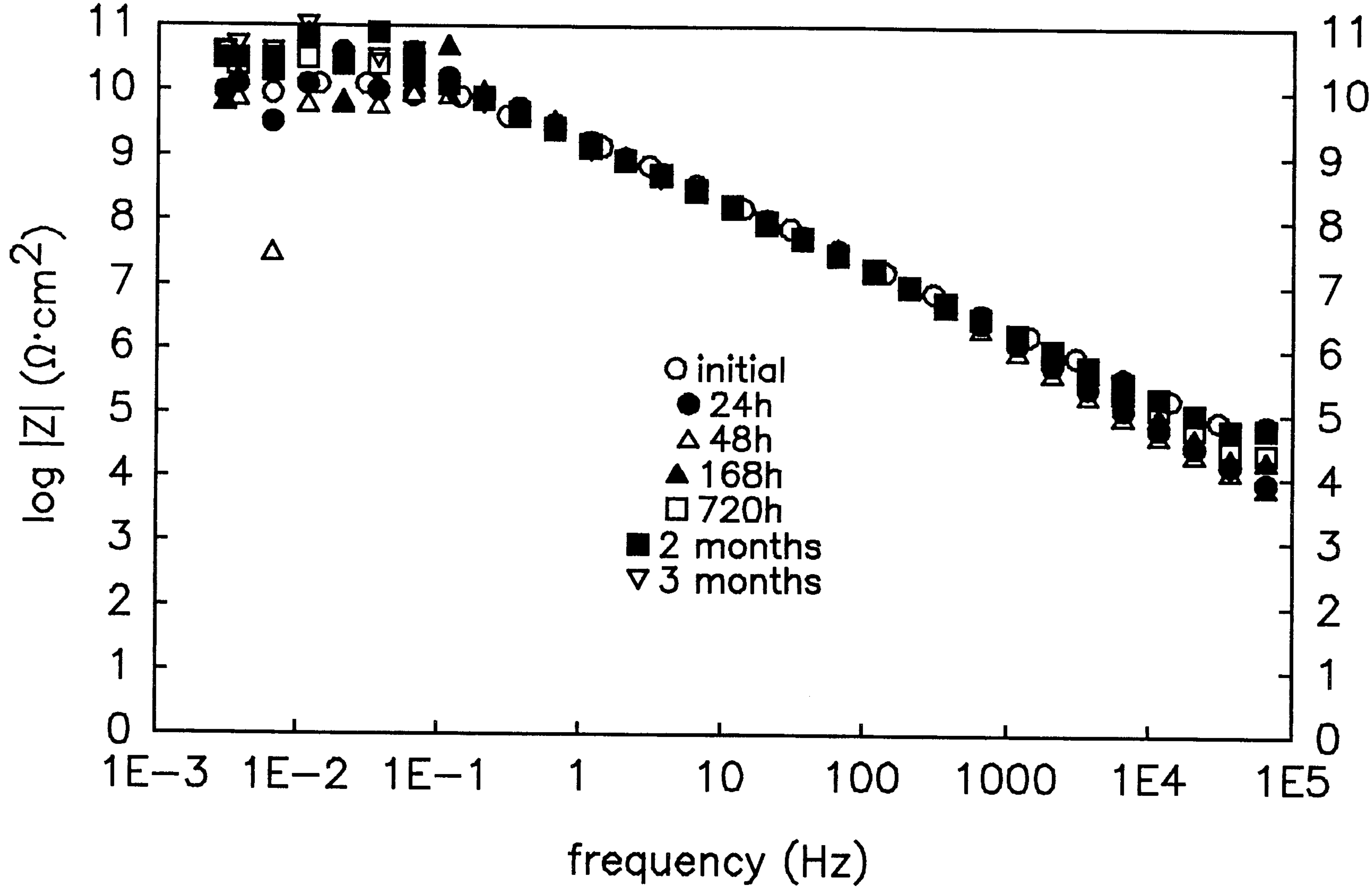

Figure 77. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in 0.01 M K_2SO_4.

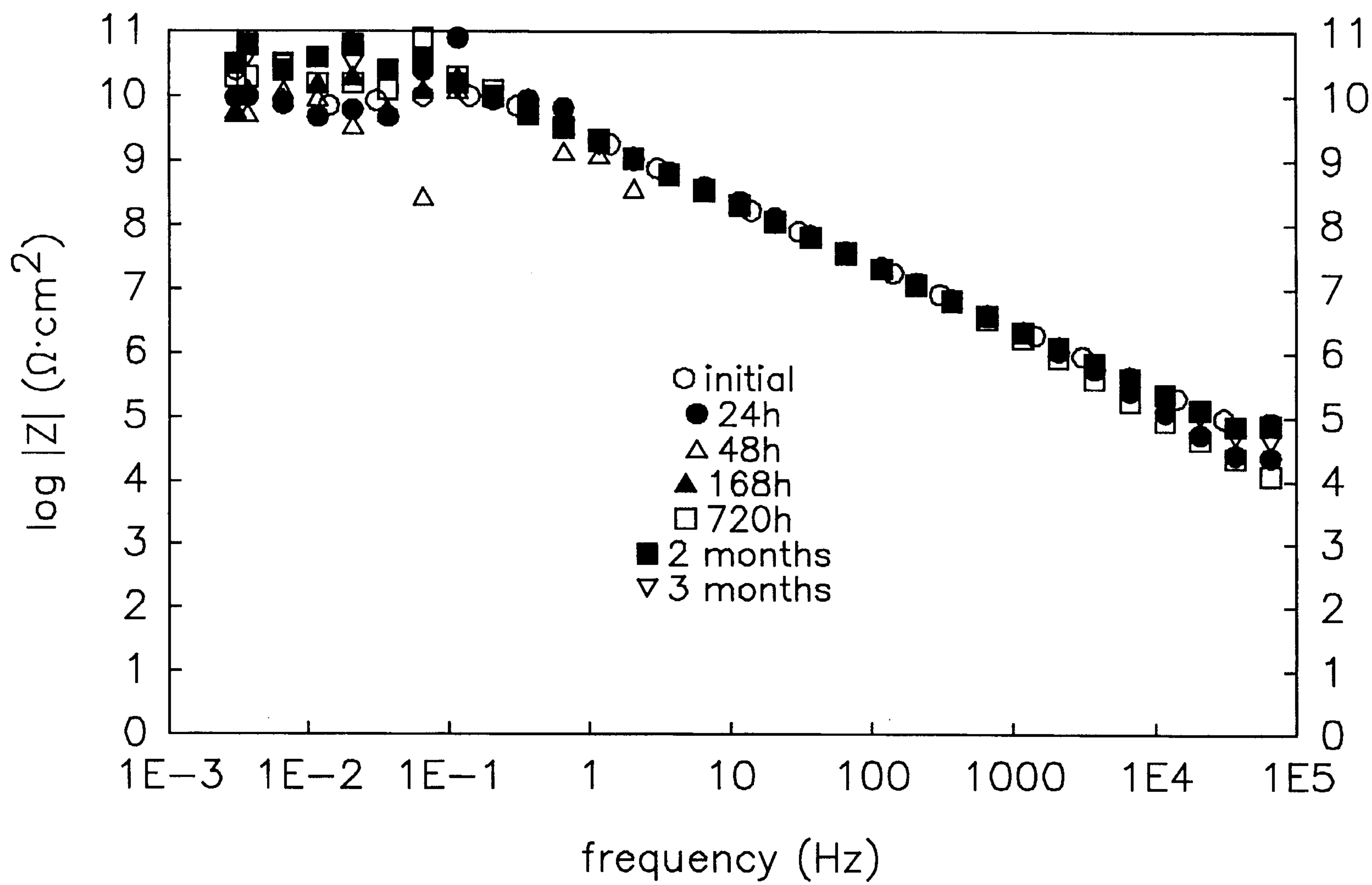

Figure 78. Impedance spectra of Epoxy 1 cured 7 d at RT on CCC Al with a 0.2 μm filter in 0.01 M K_2SO_4.

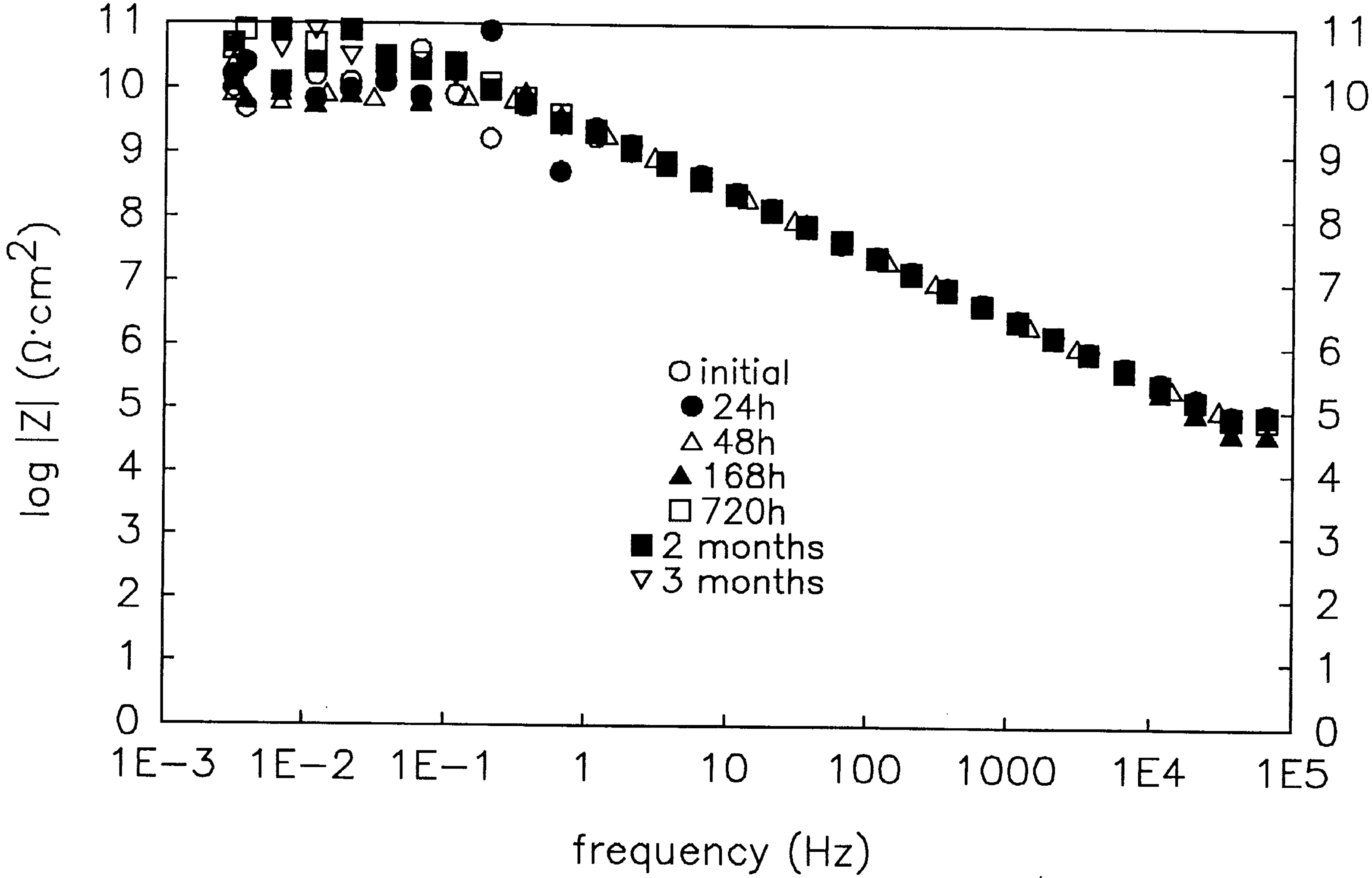

Figure 79. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 μm filter in 0.01 M K_2SO_4.

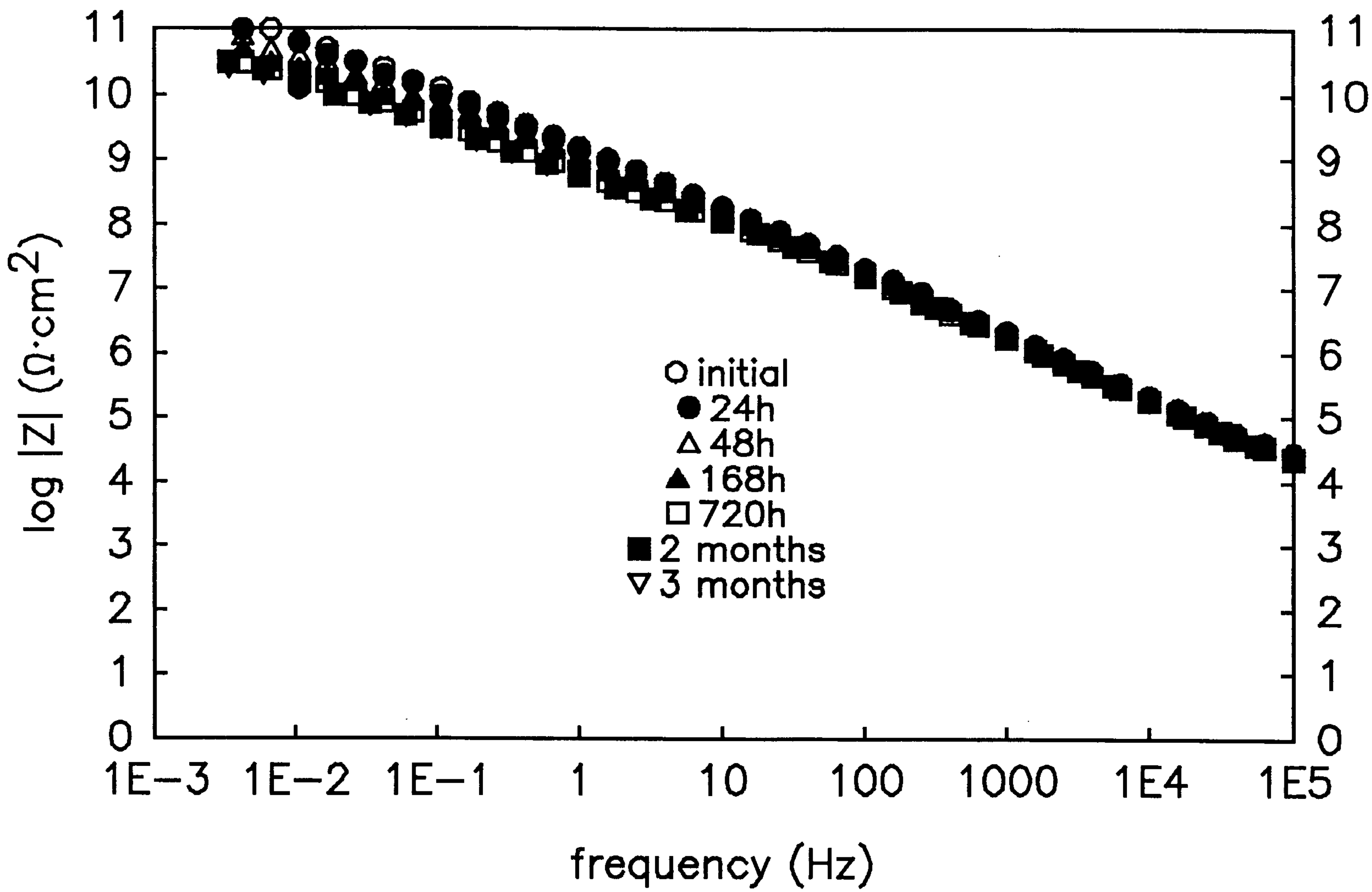

Figure 80. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in 0.01 M K_2SO_4 (Gamry system).

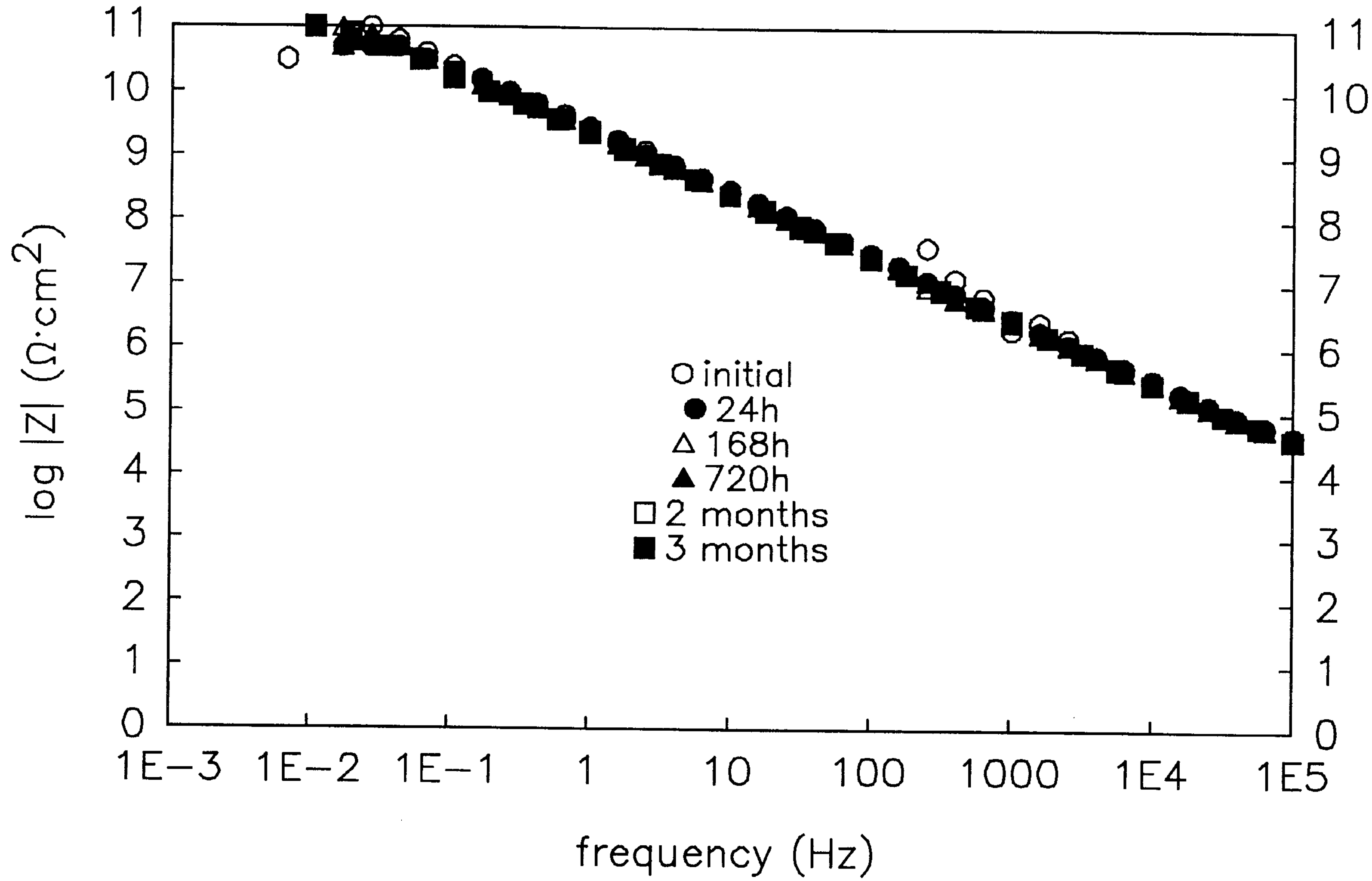

Figure 81. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 0.2 μm filter in 0.01 M K_2SO_4 (Gamry system).

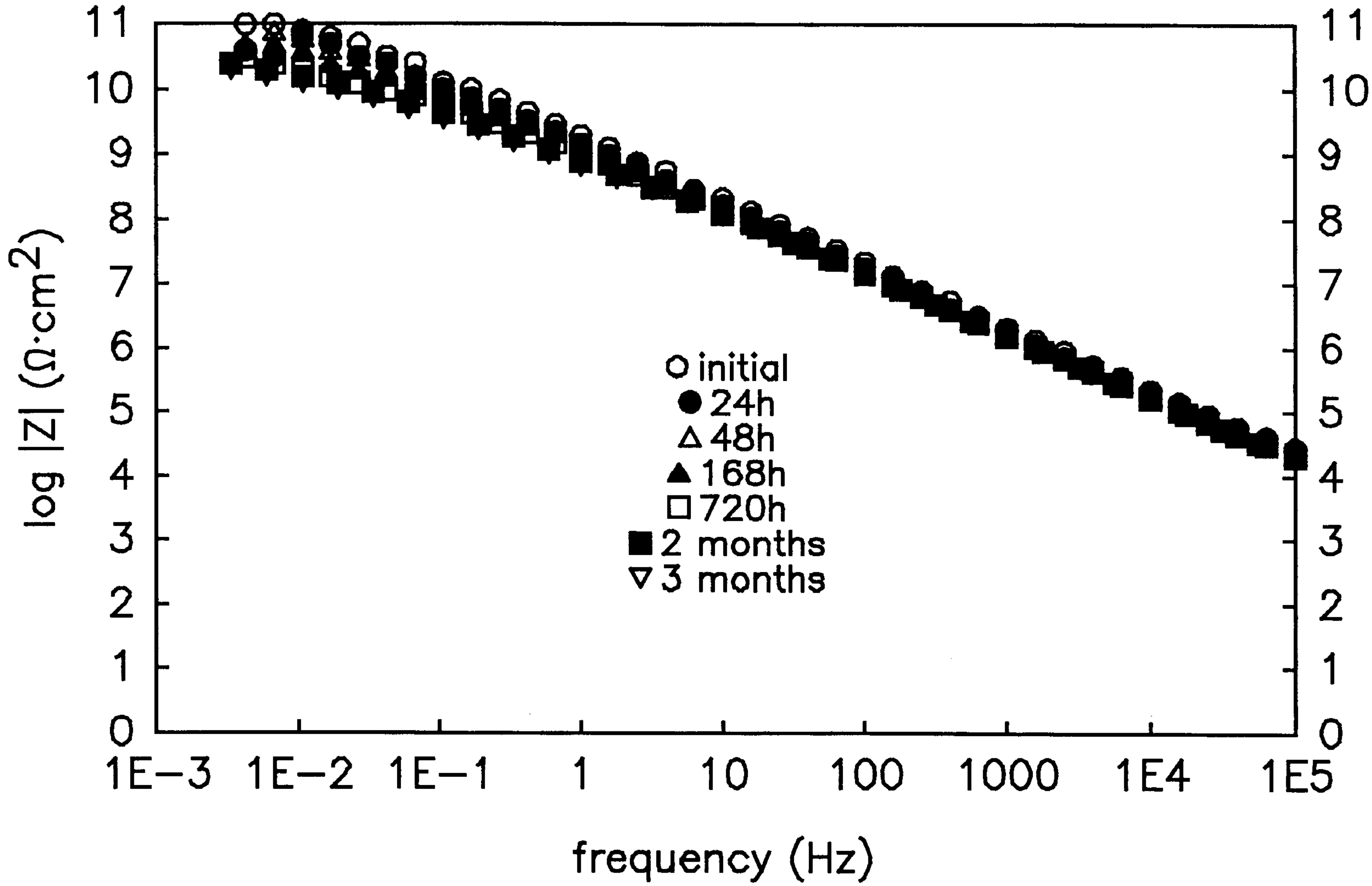

Figure 82. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in MPSi saturated 0.01 M K_2SO_4.

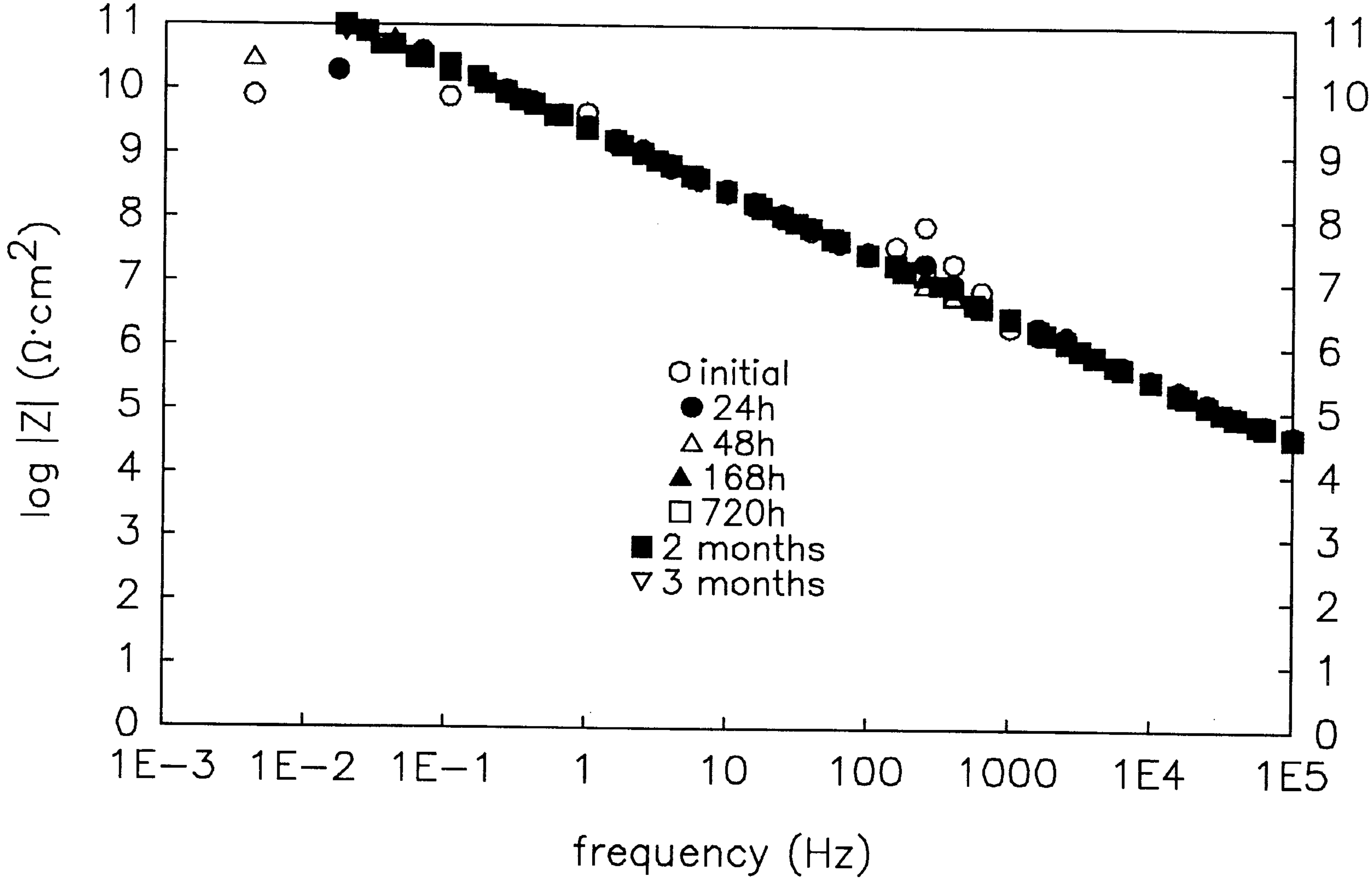

Figure 83. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 0.2 μm filter in MPSi saturated 0.01 M K_2SO_4.

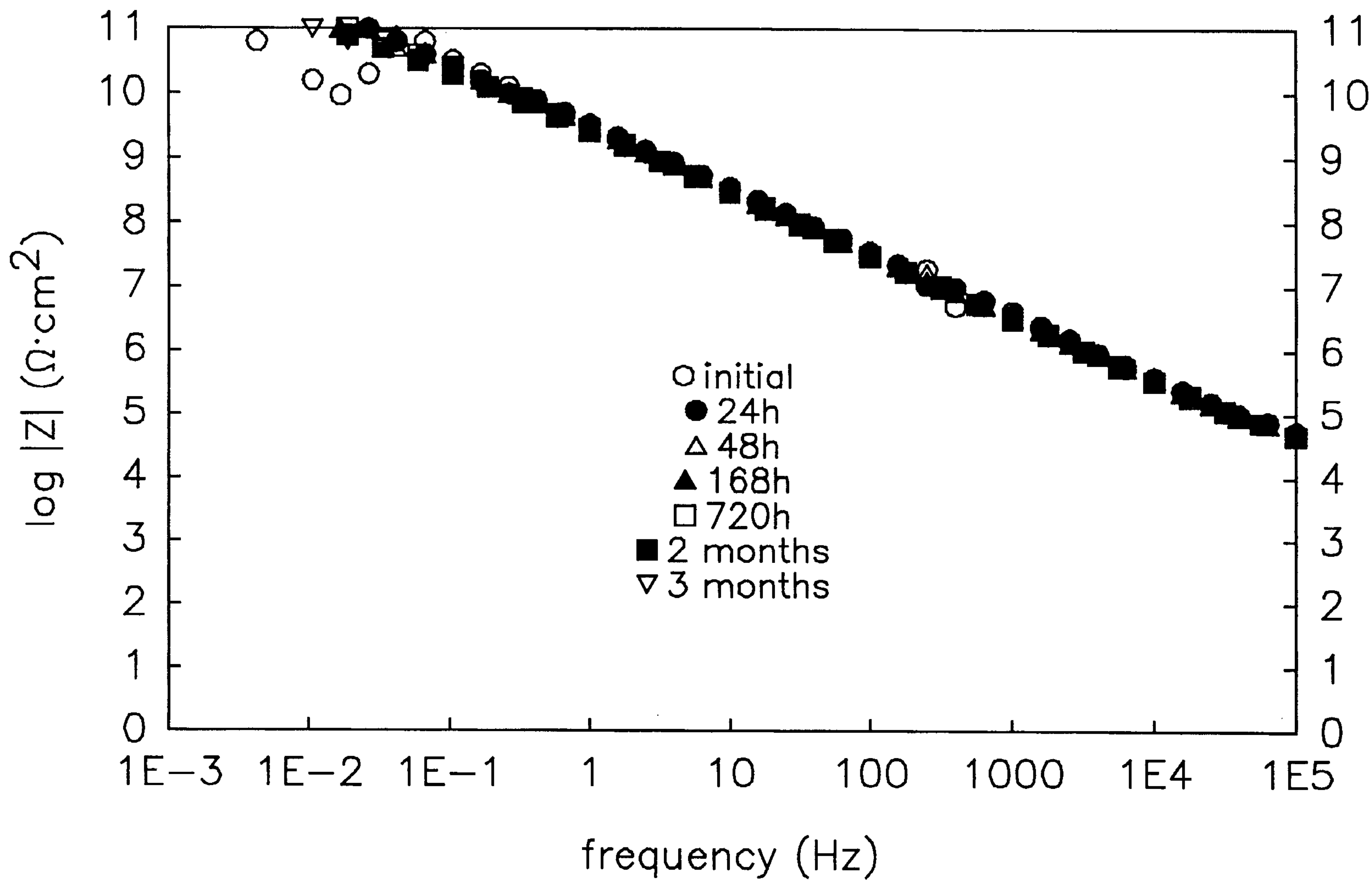

Figure 84. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 μm filter in MPSi saturated 0.01 M K_2SO_4.

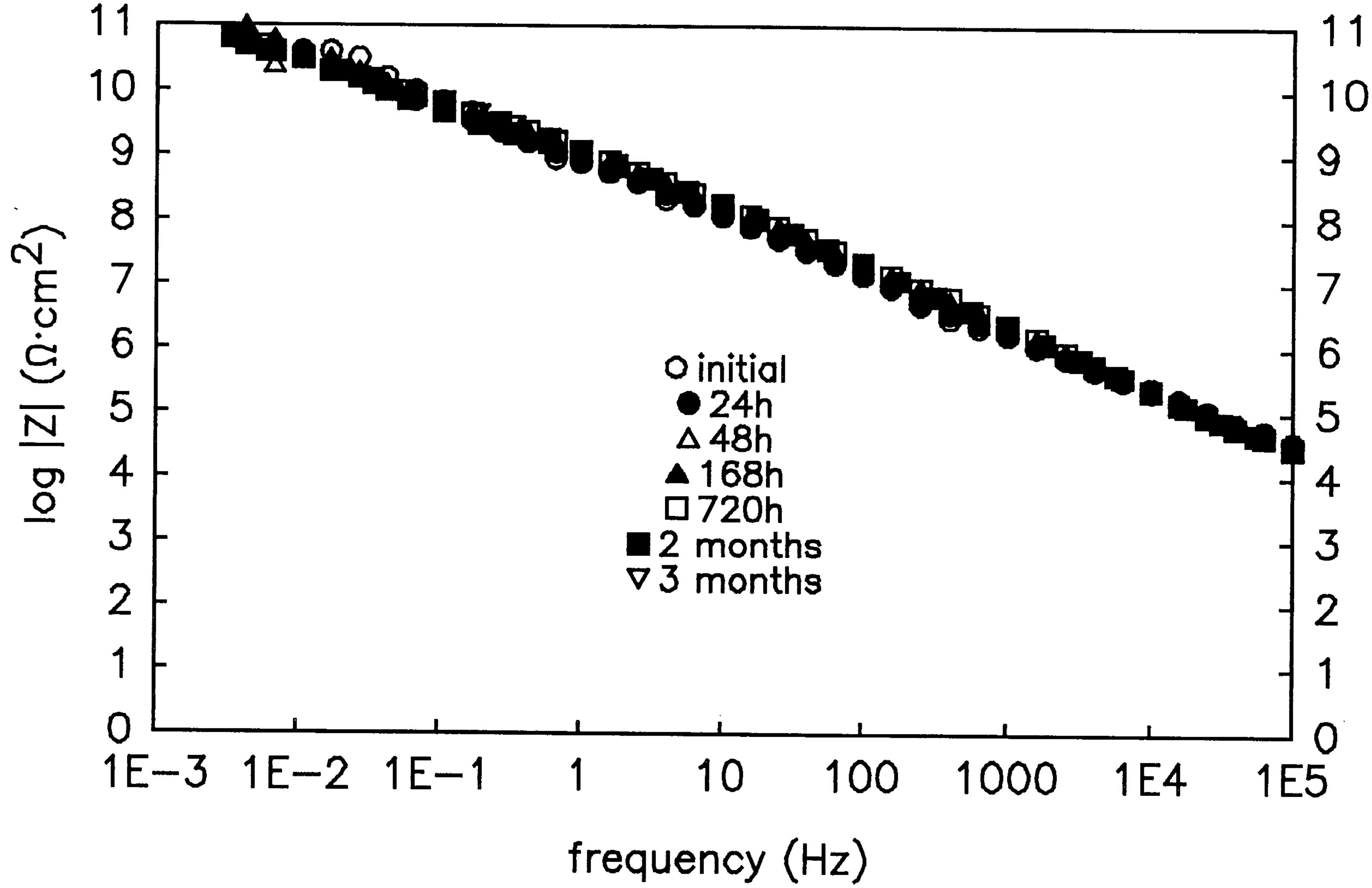

Figure 85. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in CaPSi saturated 0.01 M K_2SO_4.

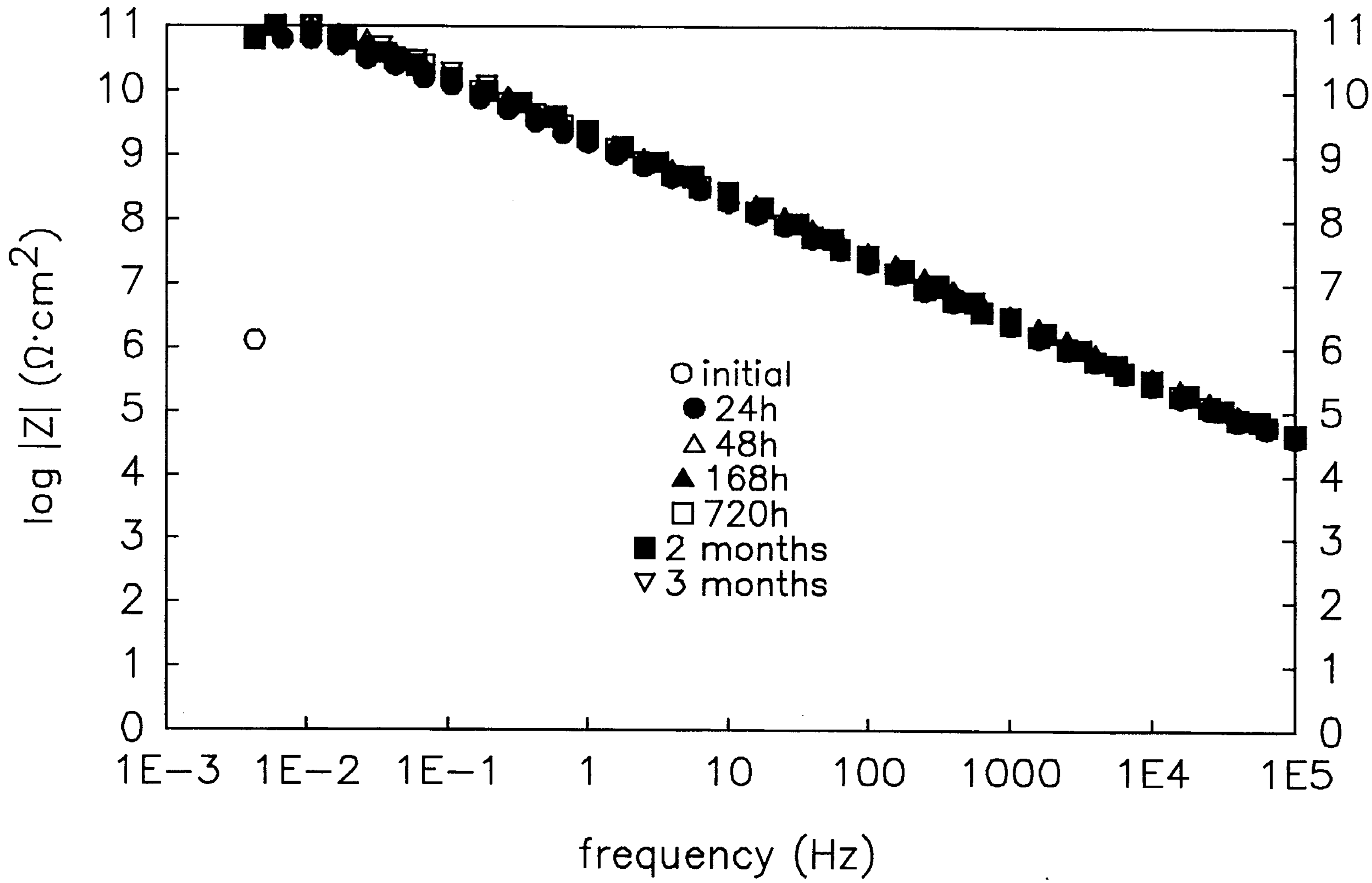

Figure 86. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 0.2 μm filter in CaPSi saturated 0.01 M K_2SO_4.

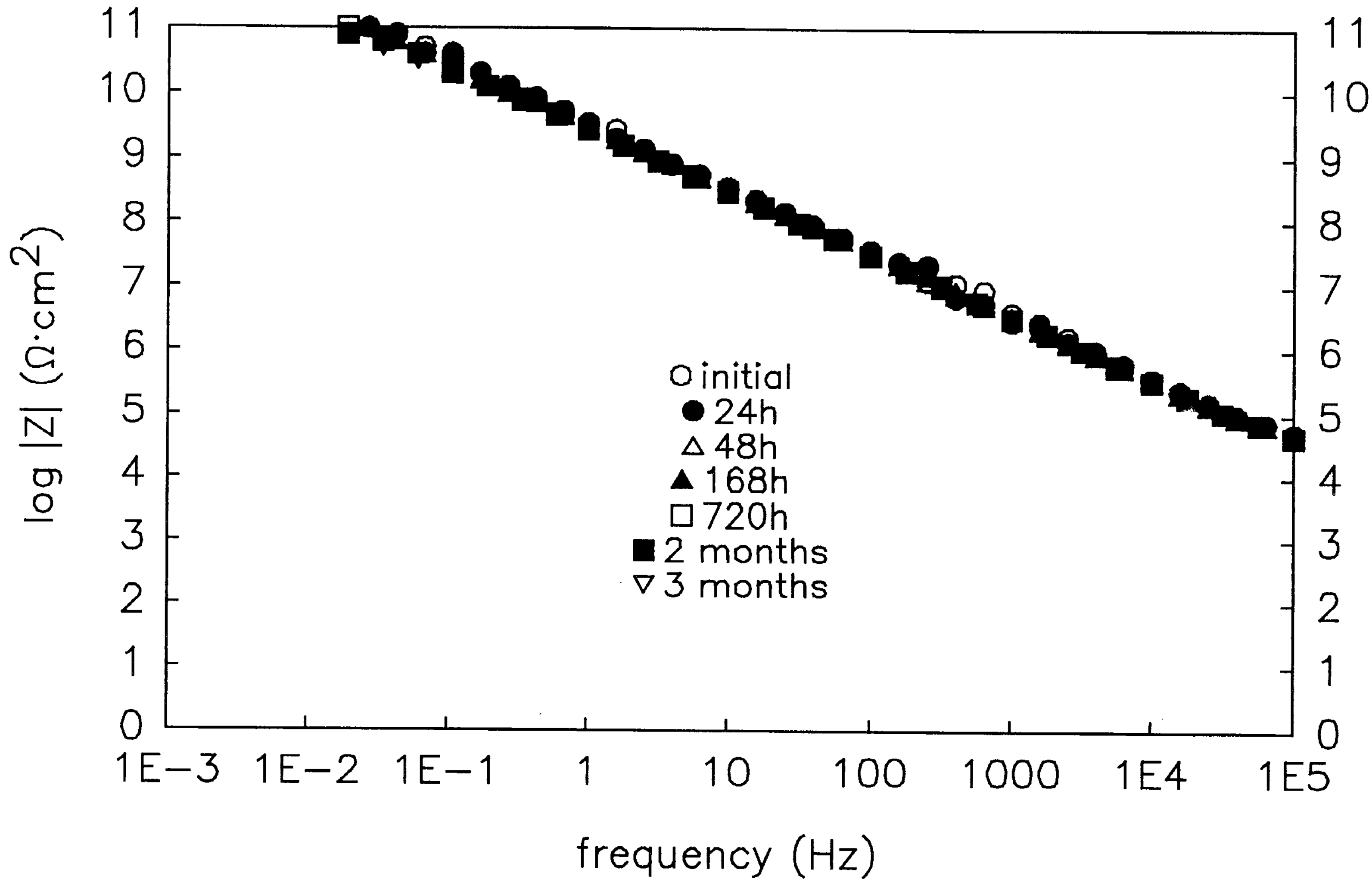

Figure 87. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 μm filter in CaPSi saturated 0.01 M K_2SO_4.

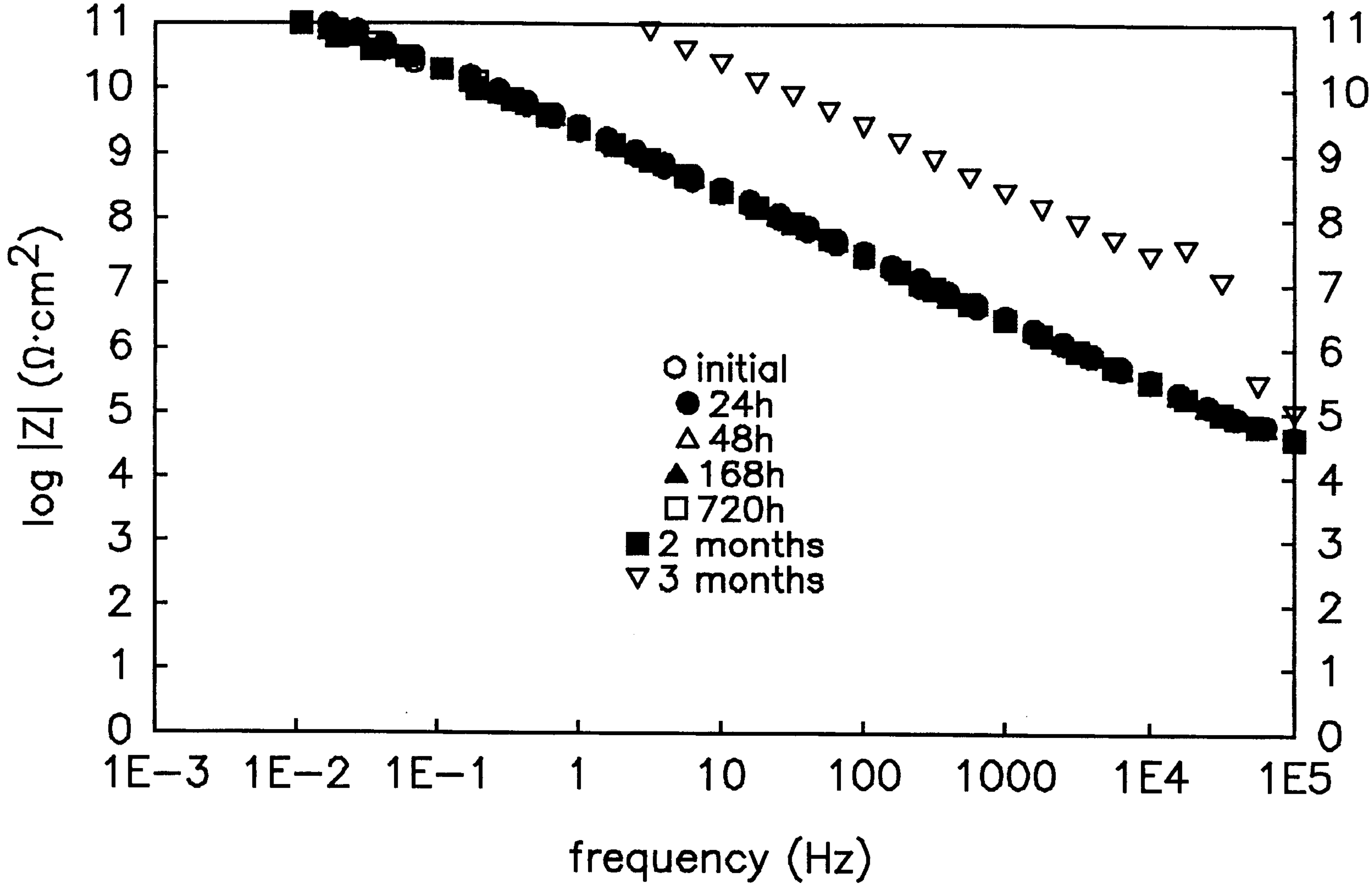

Figure 88. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in BaBor saturated 0.01 M K_2SO_4.

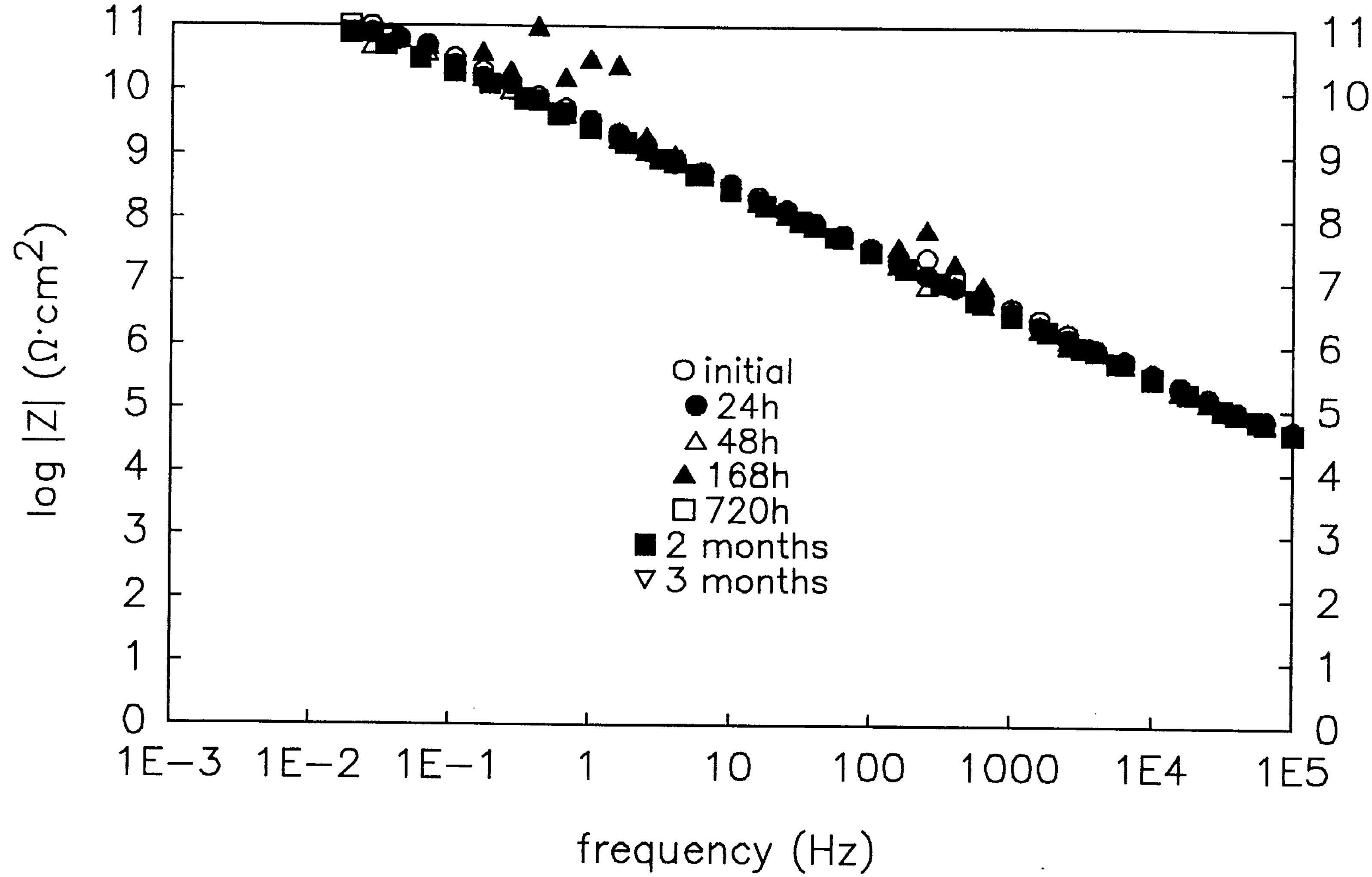

Figure 89. Impedance spectra of Epoxy 1 cured 7 d at RT on CCC Al with a 0.2 μm filter in BaBor saturated 0.01 M K_2SO_4.

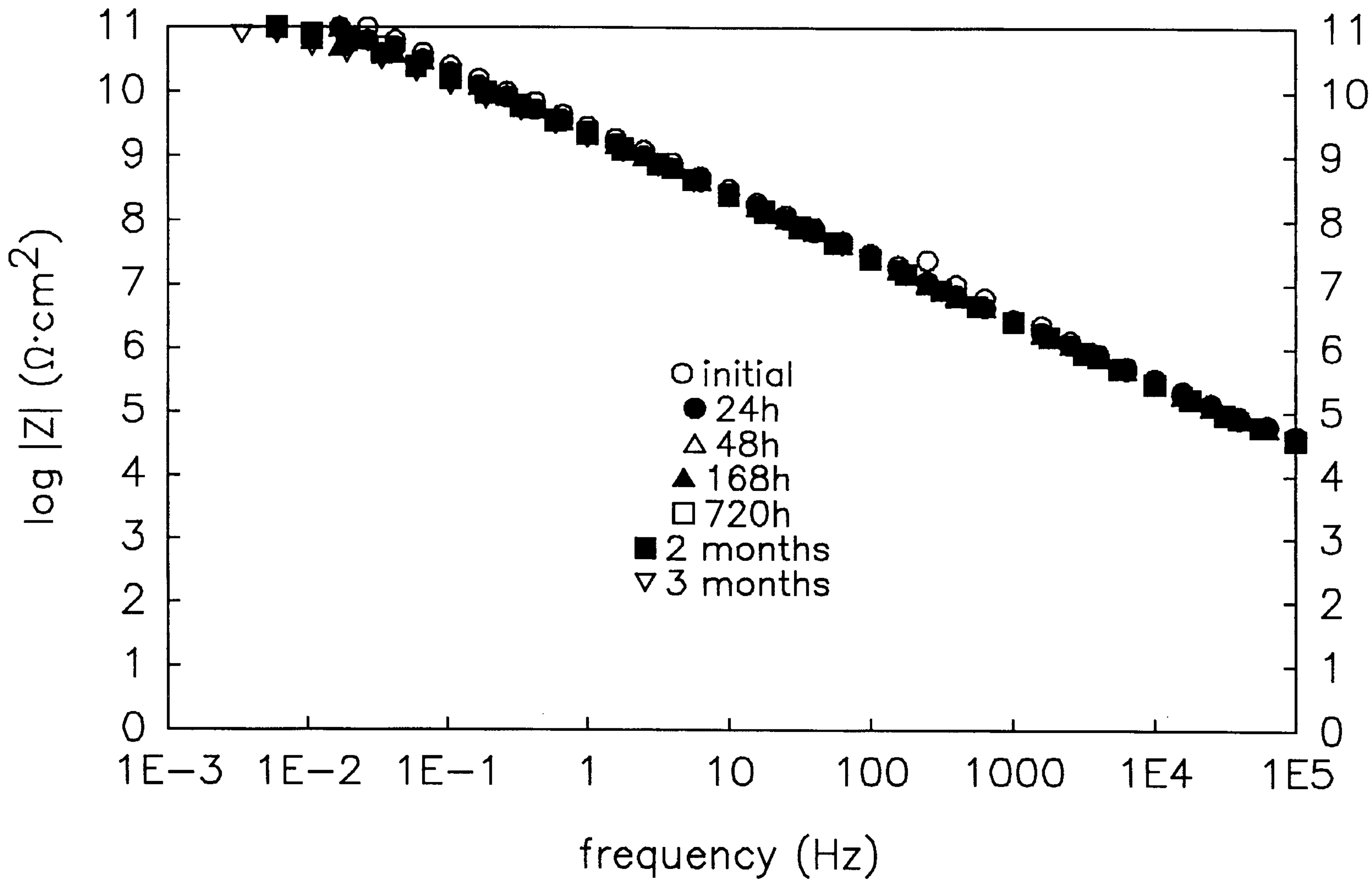

Figure 90. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 μm filter in BaBor saturated 0.01 M K_2SO_4.

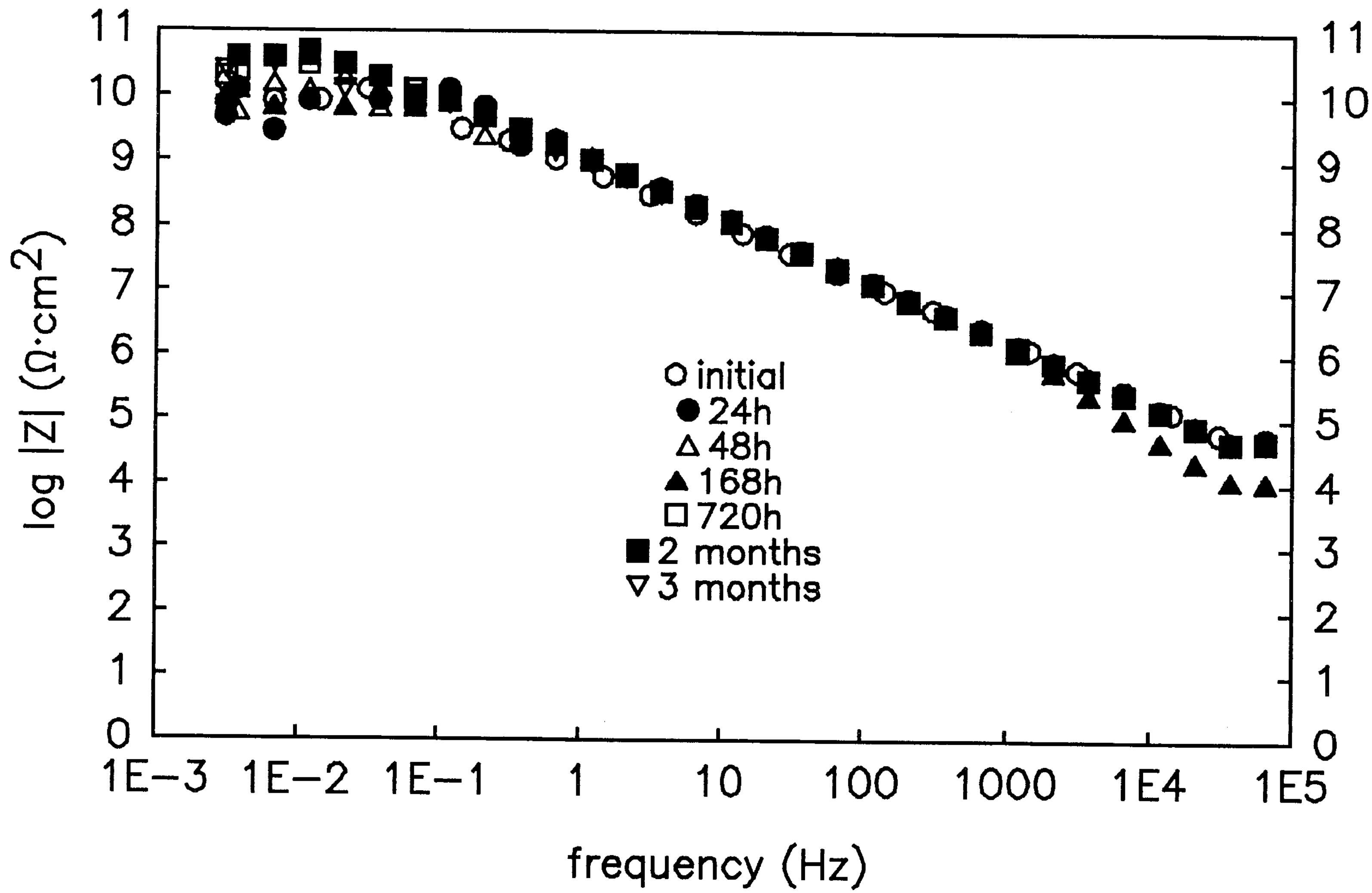

Figure 91. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in ZnoN saturated 0.01 M K_2SO_4.

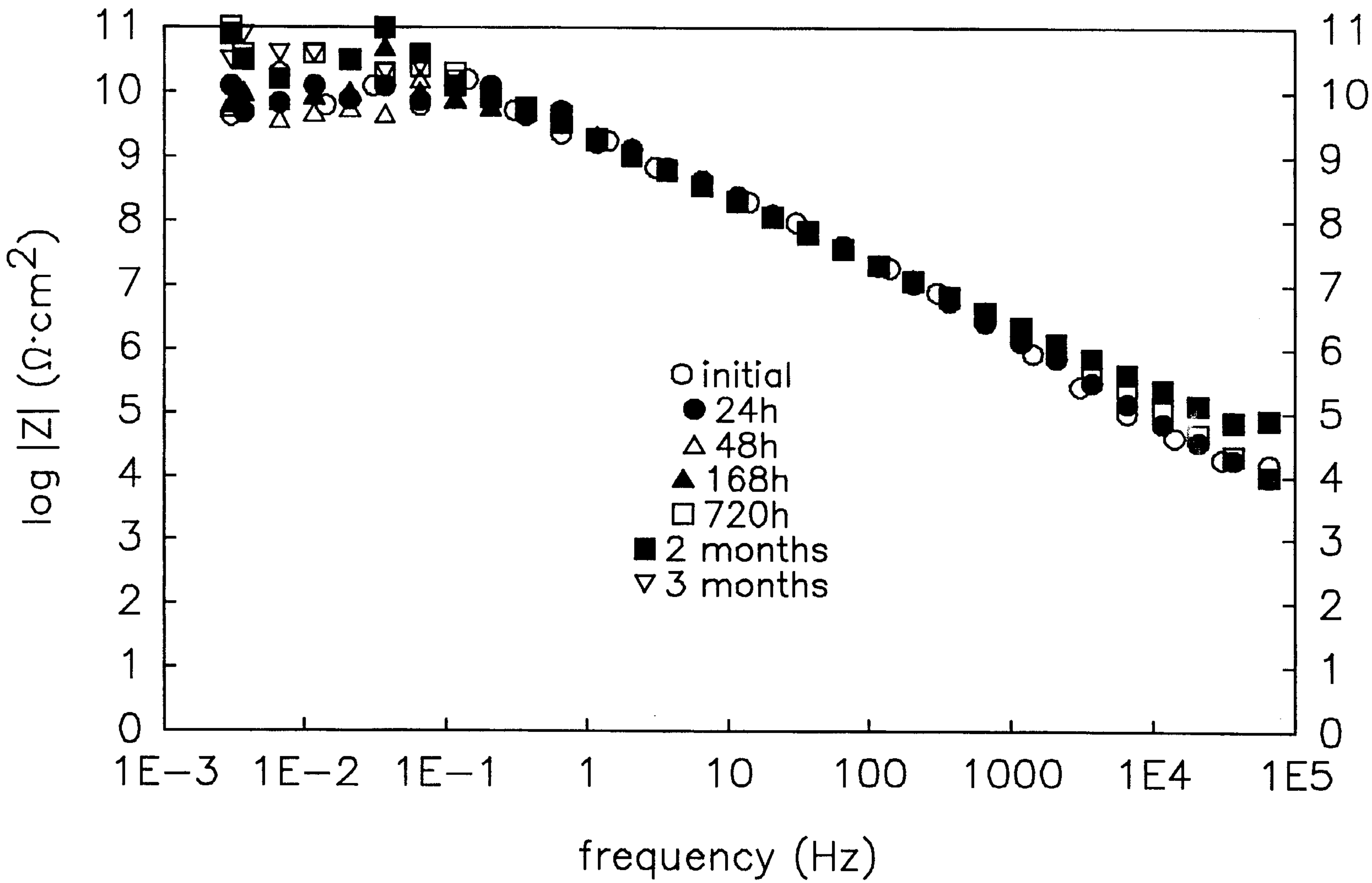

Figure 92. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 0.2 μm filter in ZnoN saturated 0.01 M K_2SO_4.

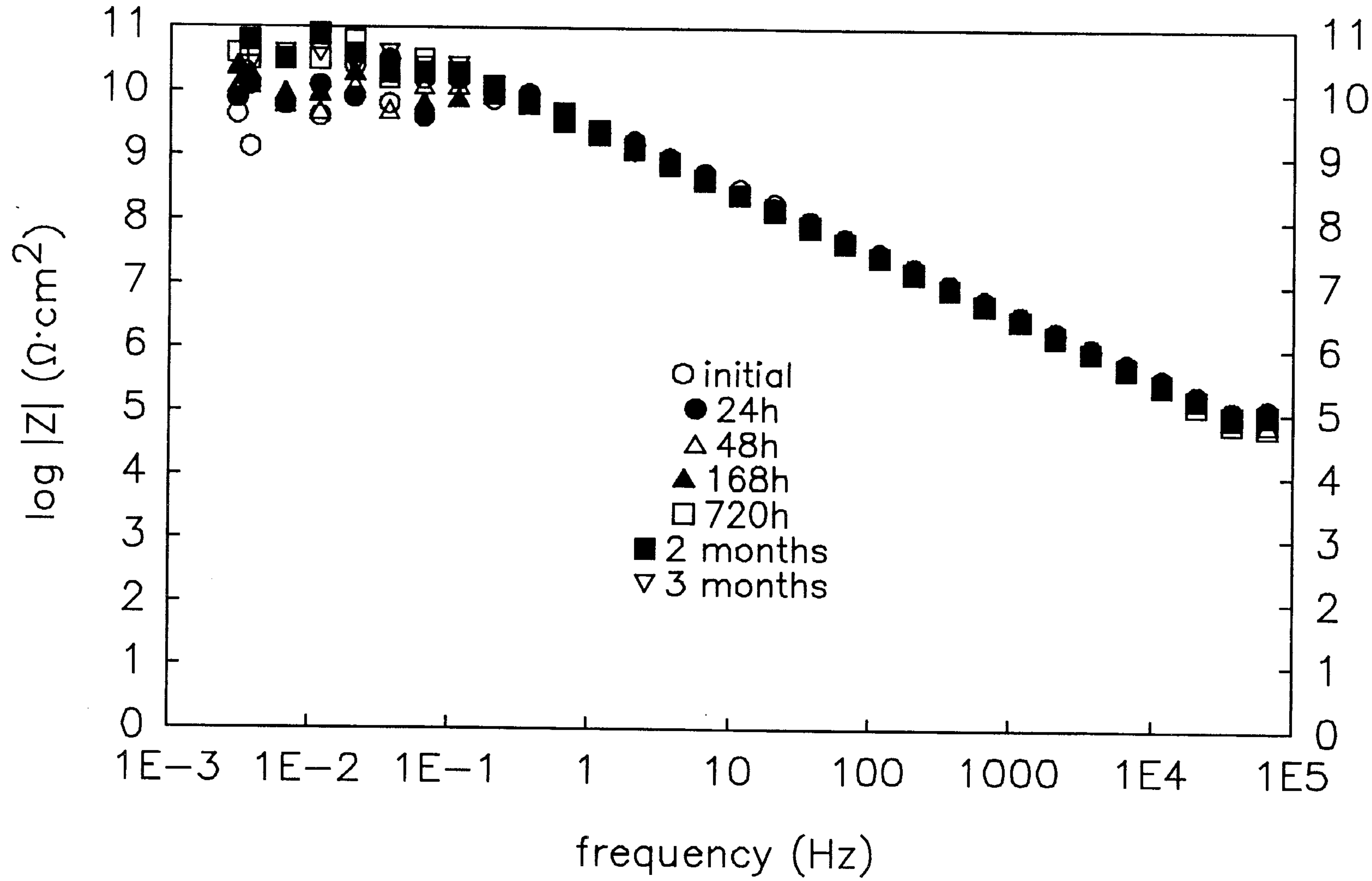

Figure 93. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 μm filter in ZnoN saturated 0.01 M K_2SO_4.

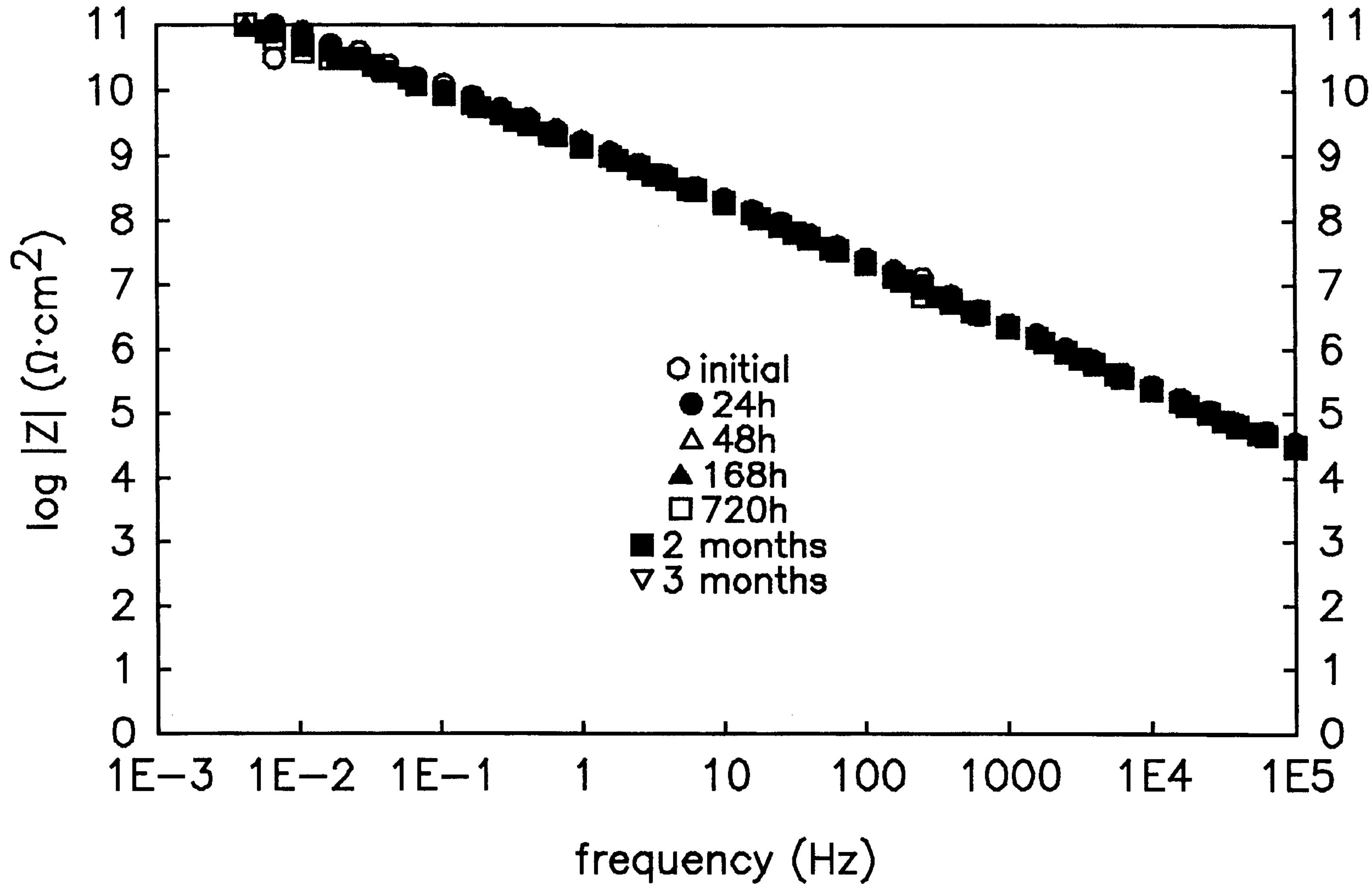

Figure 94. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in ZnAlP saturated 0.01 M K_2SO_4.

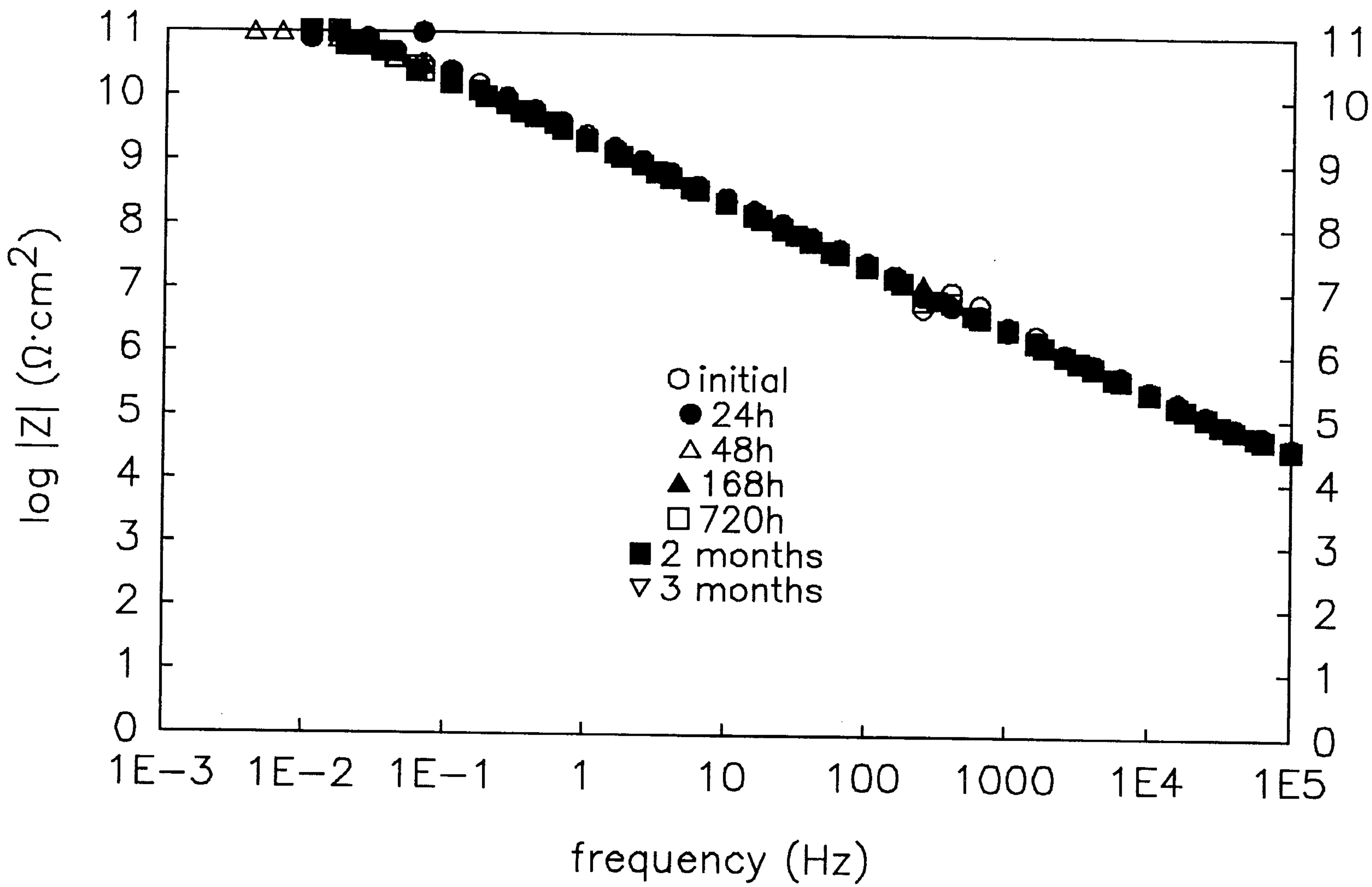

Figure 95. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 0.2 μm filter in ZnAlP saturated 0.01 M K_2SO_4.

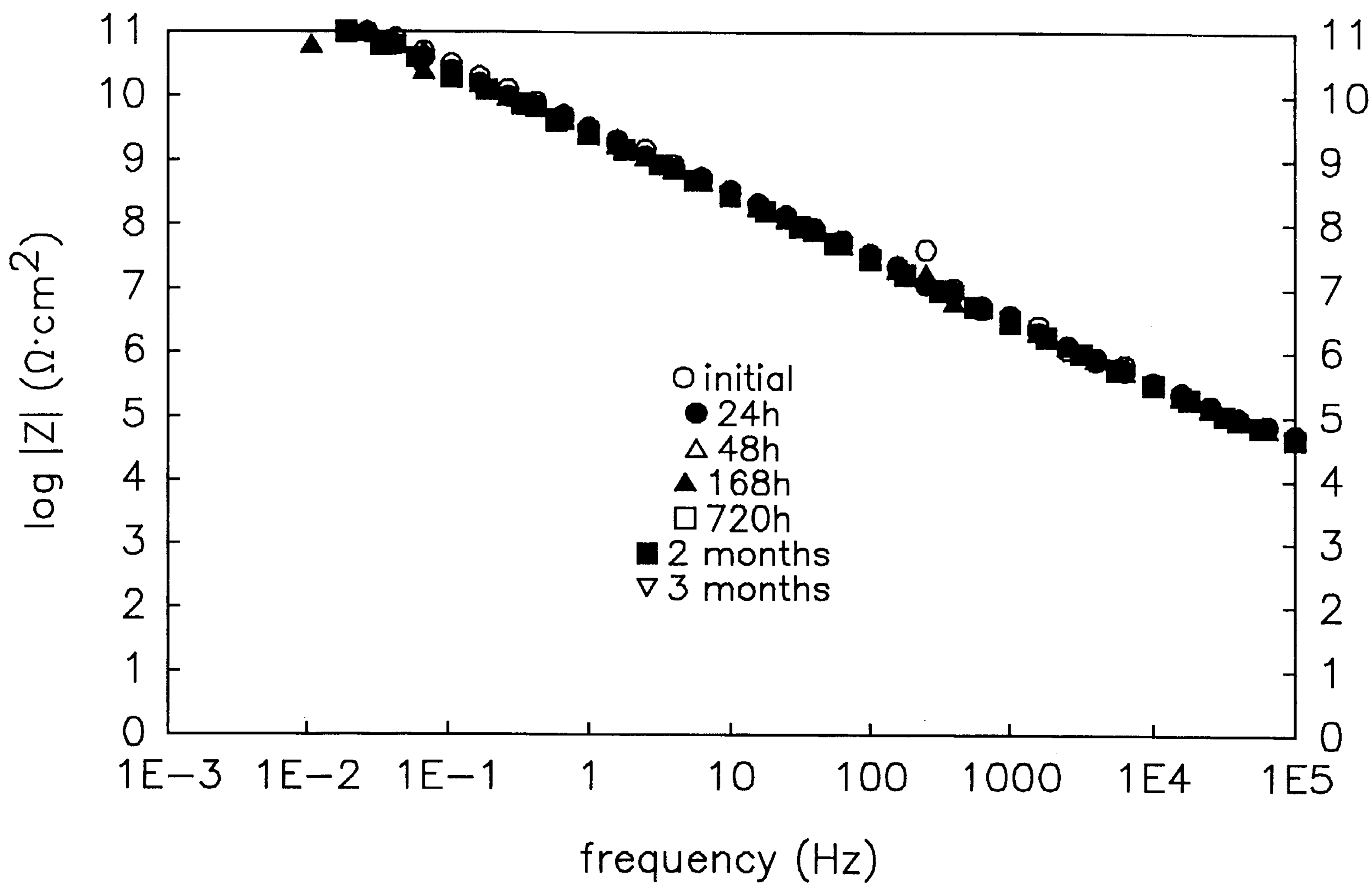

Figure 96. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 µm filter in ZnAlP saturated 0.01 M K_2SO_4.

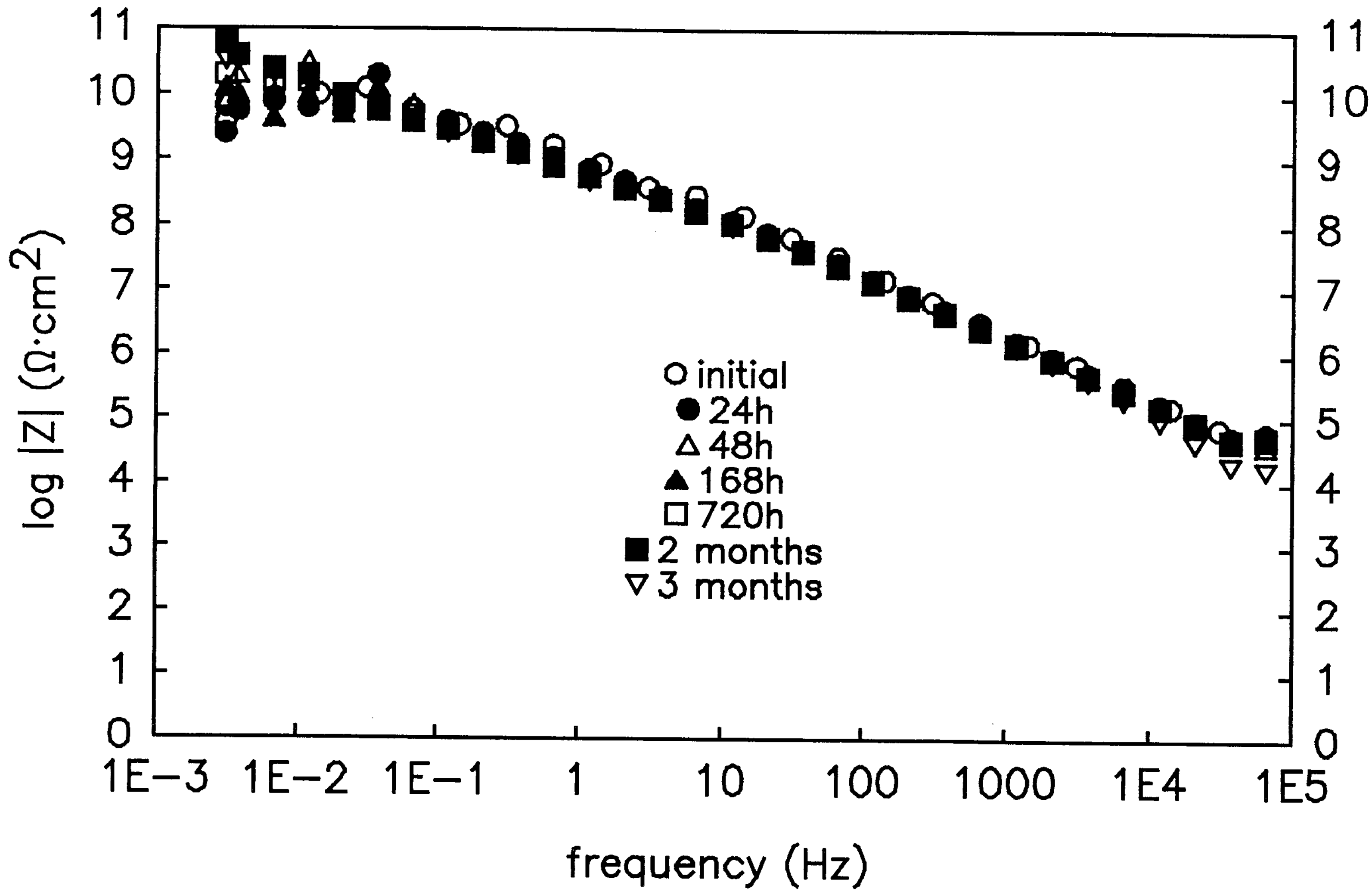

Figure 97. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in M1PSi saturated 0.01 M K_2SO_4.

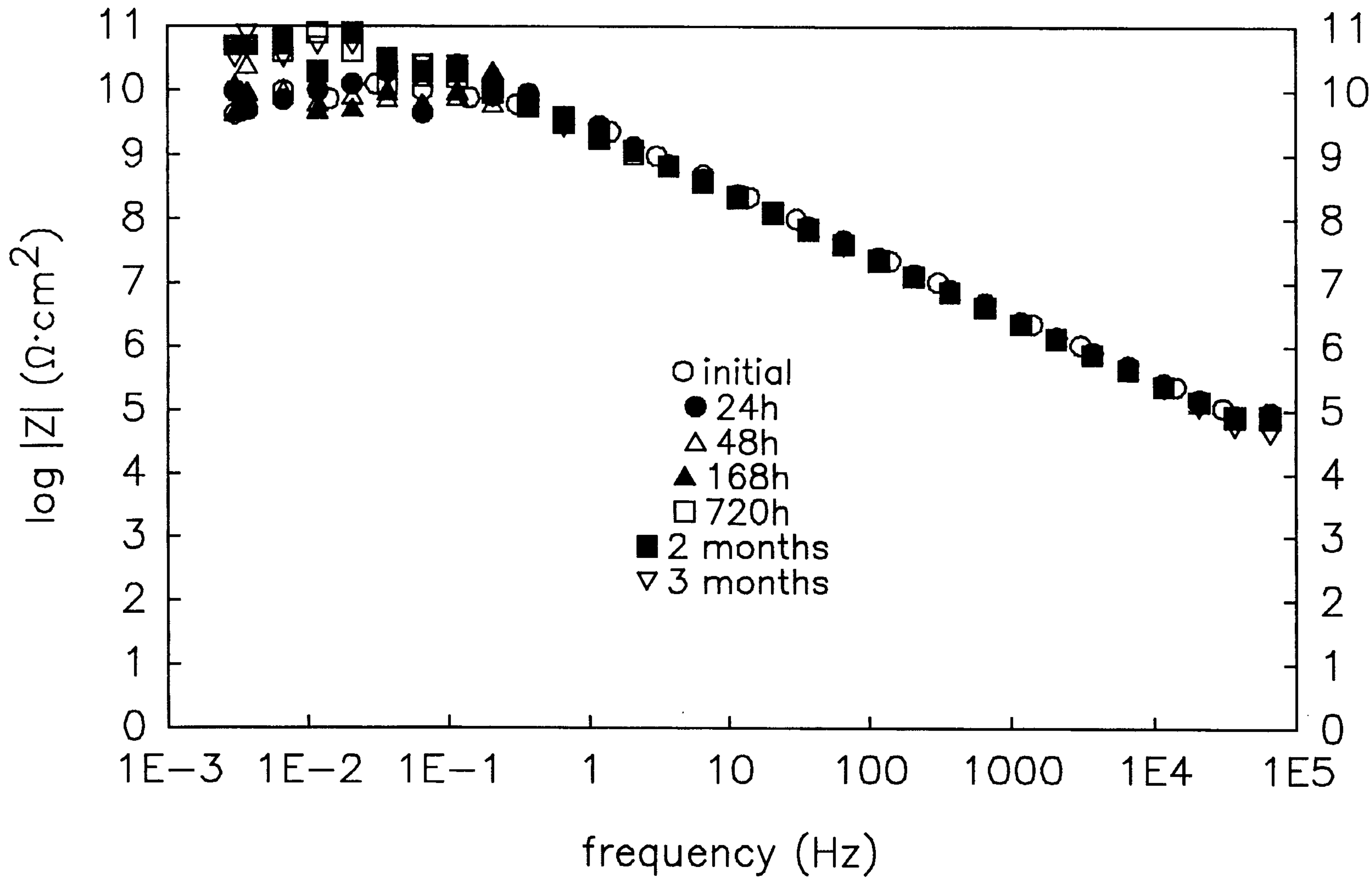

Figure 98. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 0.2 μm filter in M1PSi saturated 0.01 M K_2SO_4.

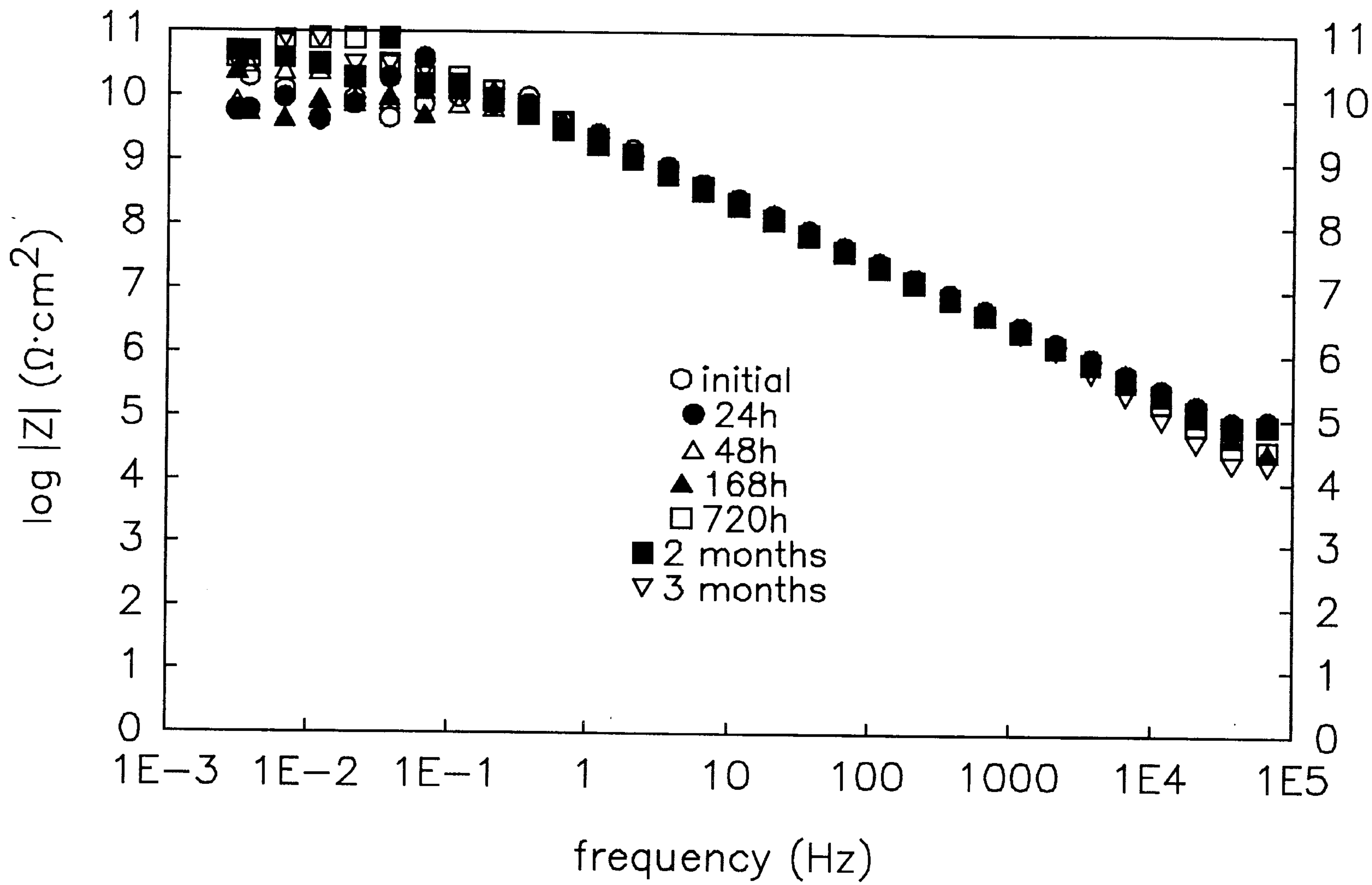

Figure 99. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 μm filter in M1PSi saturated 0.01 M K_2SO_4.

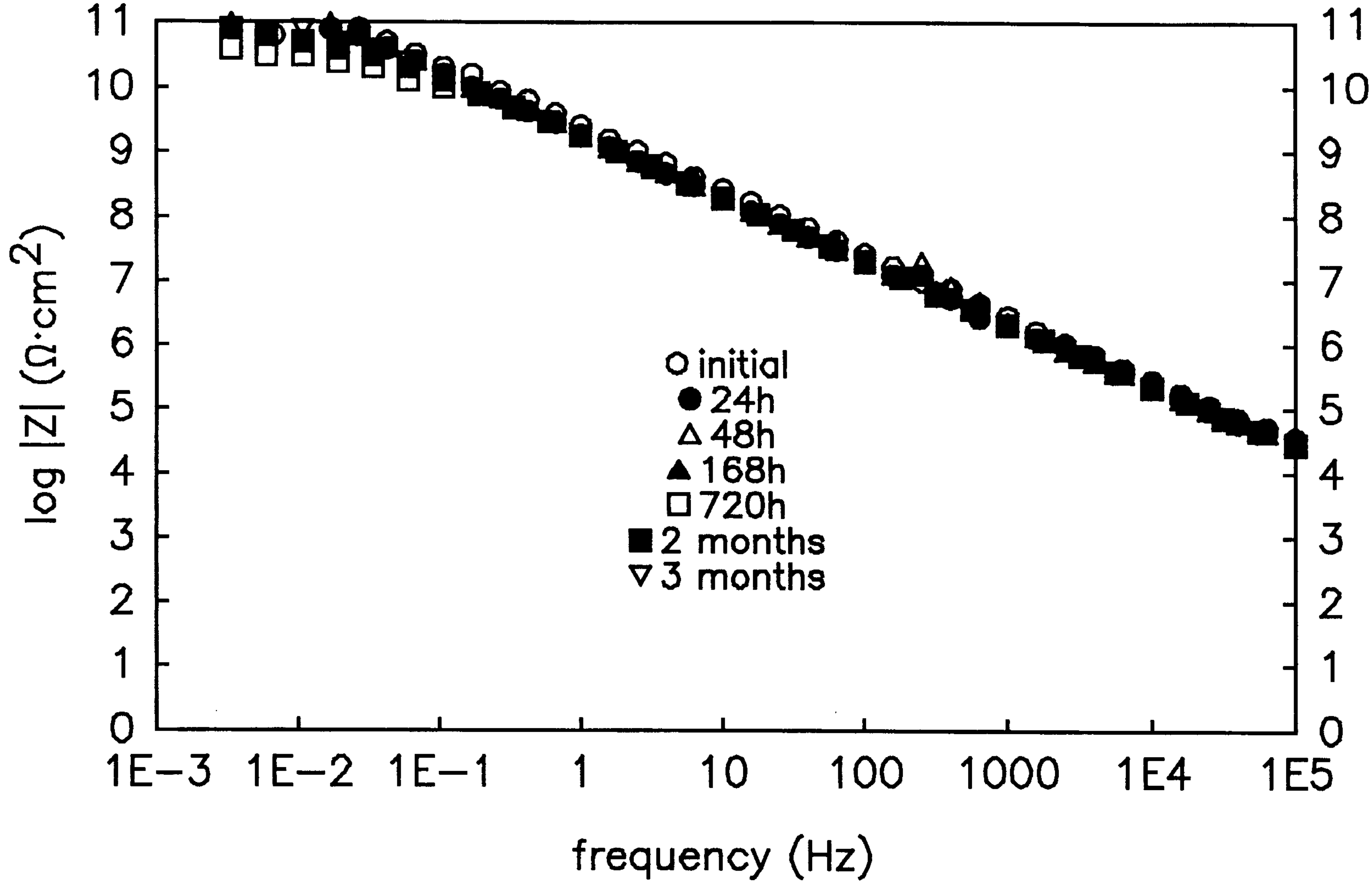

Figure 100. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in CaSi saturated 0.01 M K_2SO_4.

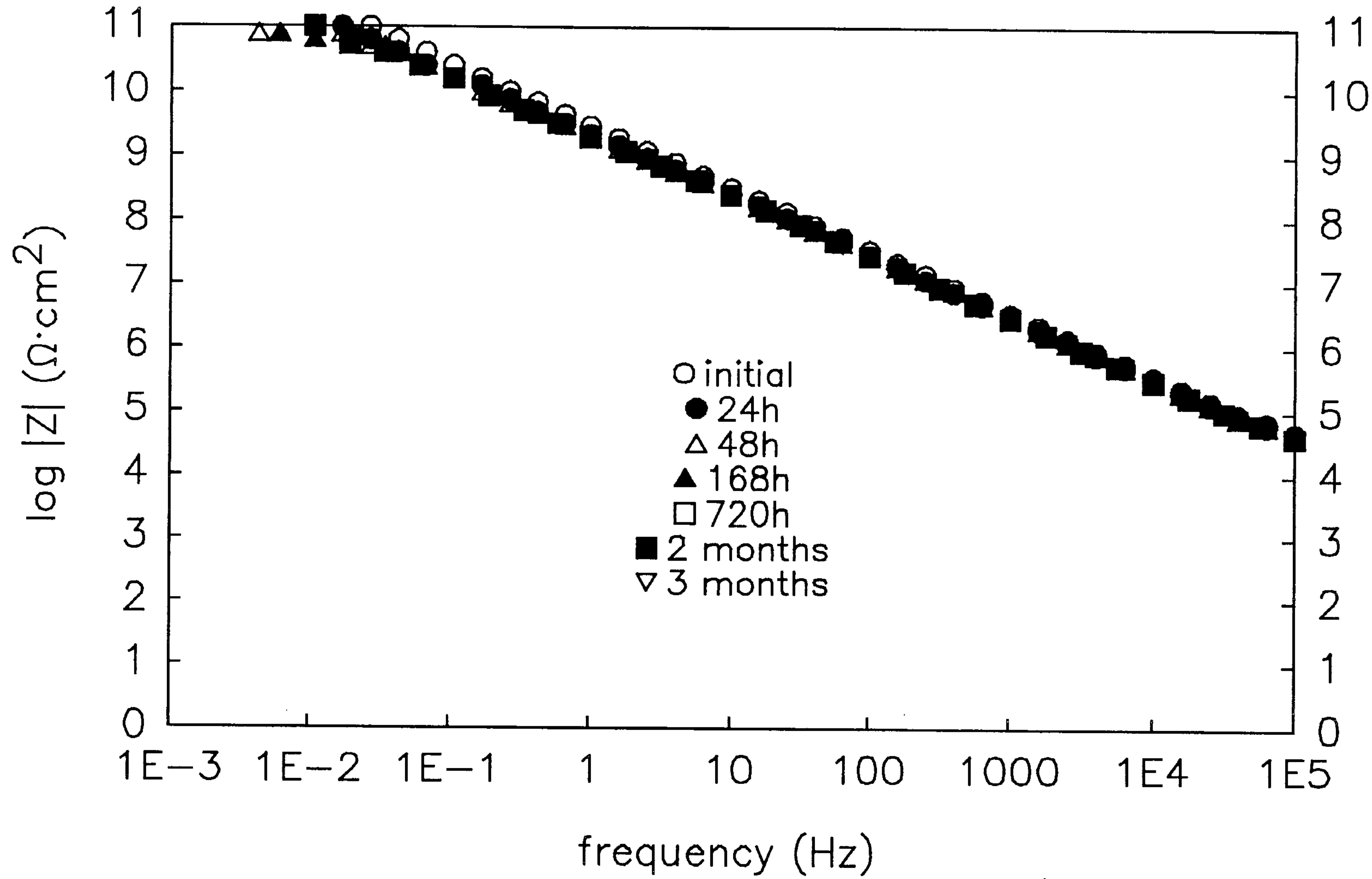

Figure 101. Impedance spectra of Epoxy 1 cured 7 d at RT on CCC Al with a 0.2 μm filter in CaSi saturated 0.01 M K_2SO_4.

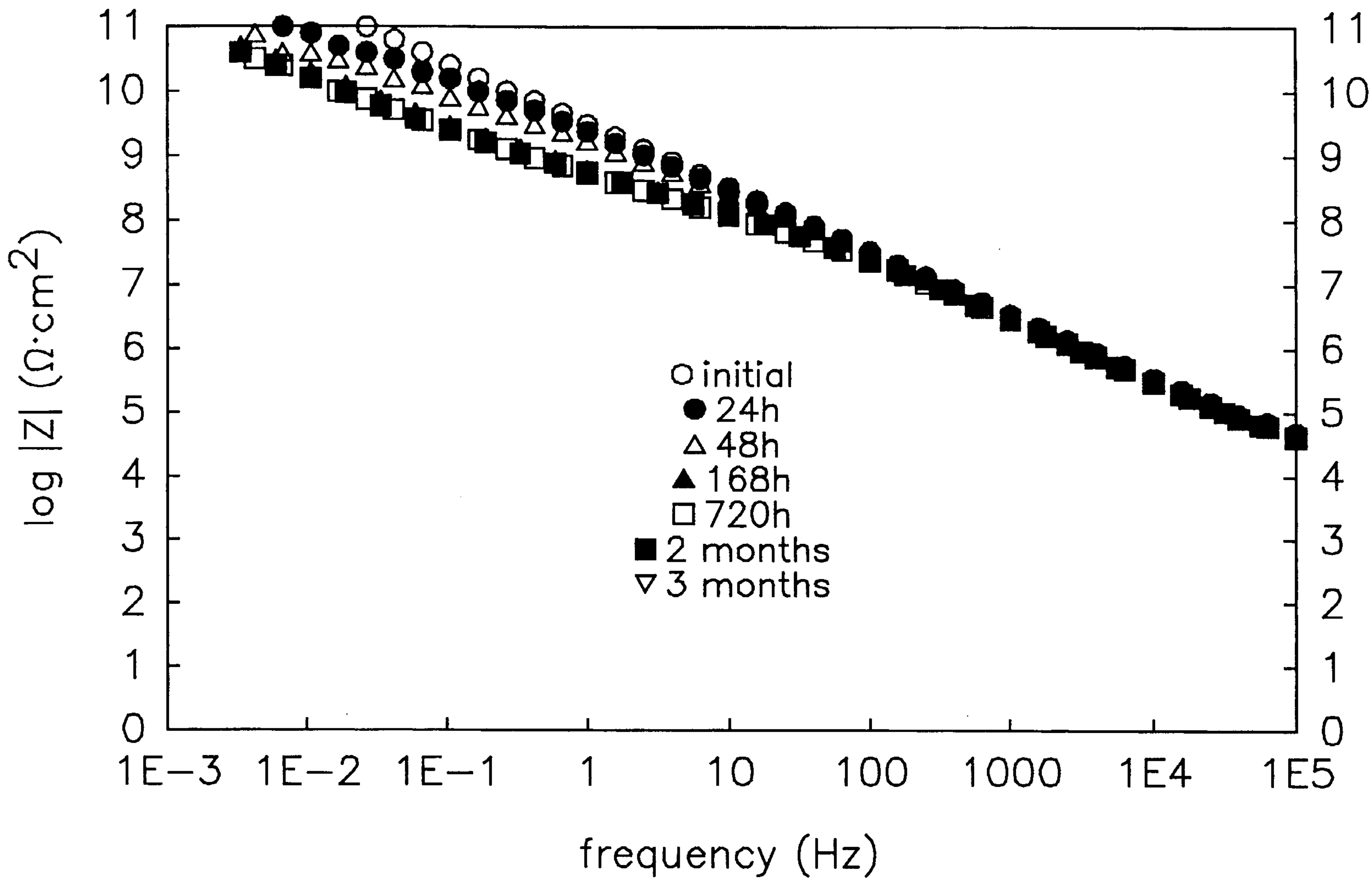

Figure 102. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 μm filter in CaSi saturated 0.01 M K_2SO_4.

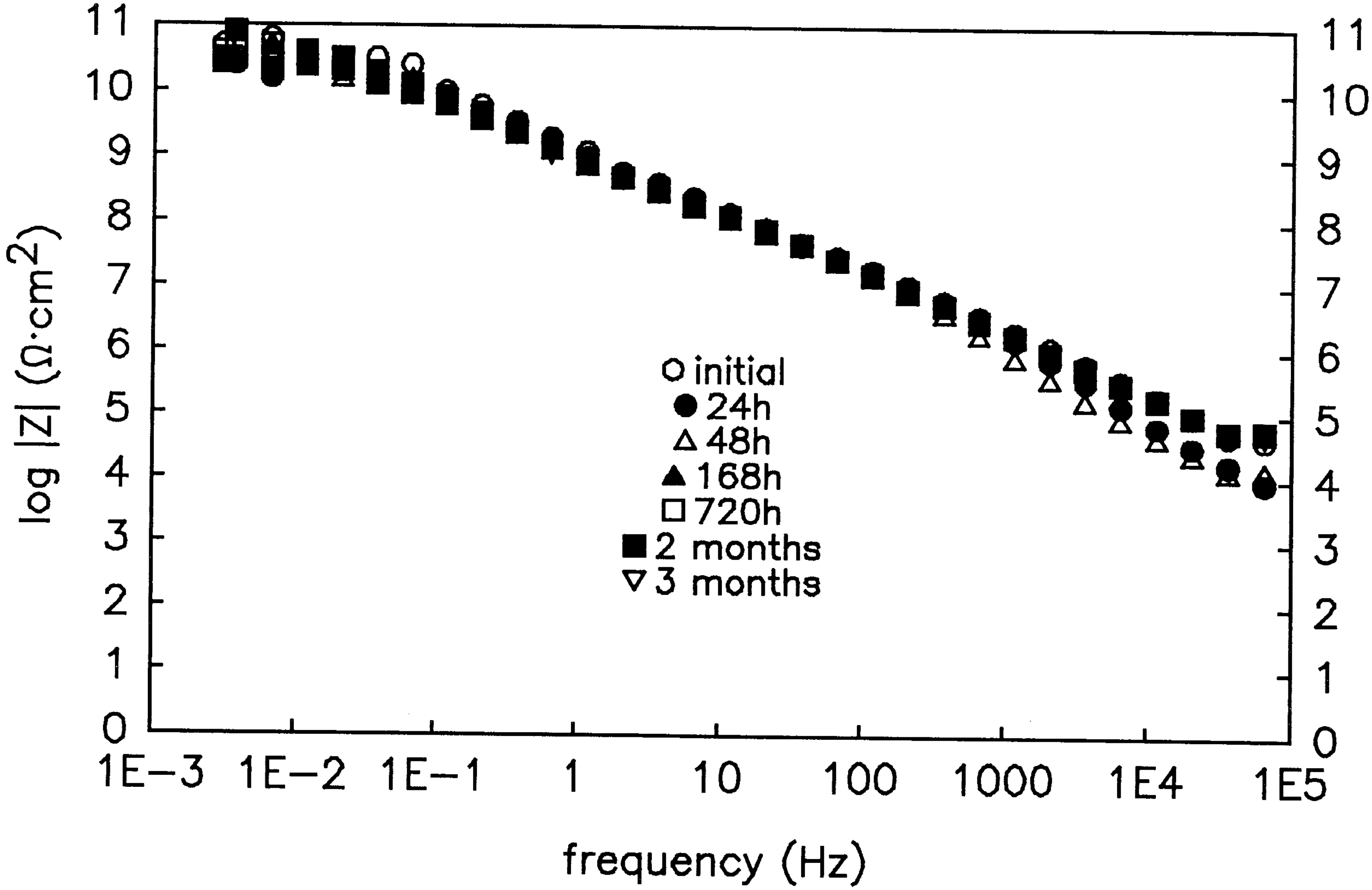

Figure 103. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in ZnMoP saturated 0.01 M K_2SO_4.

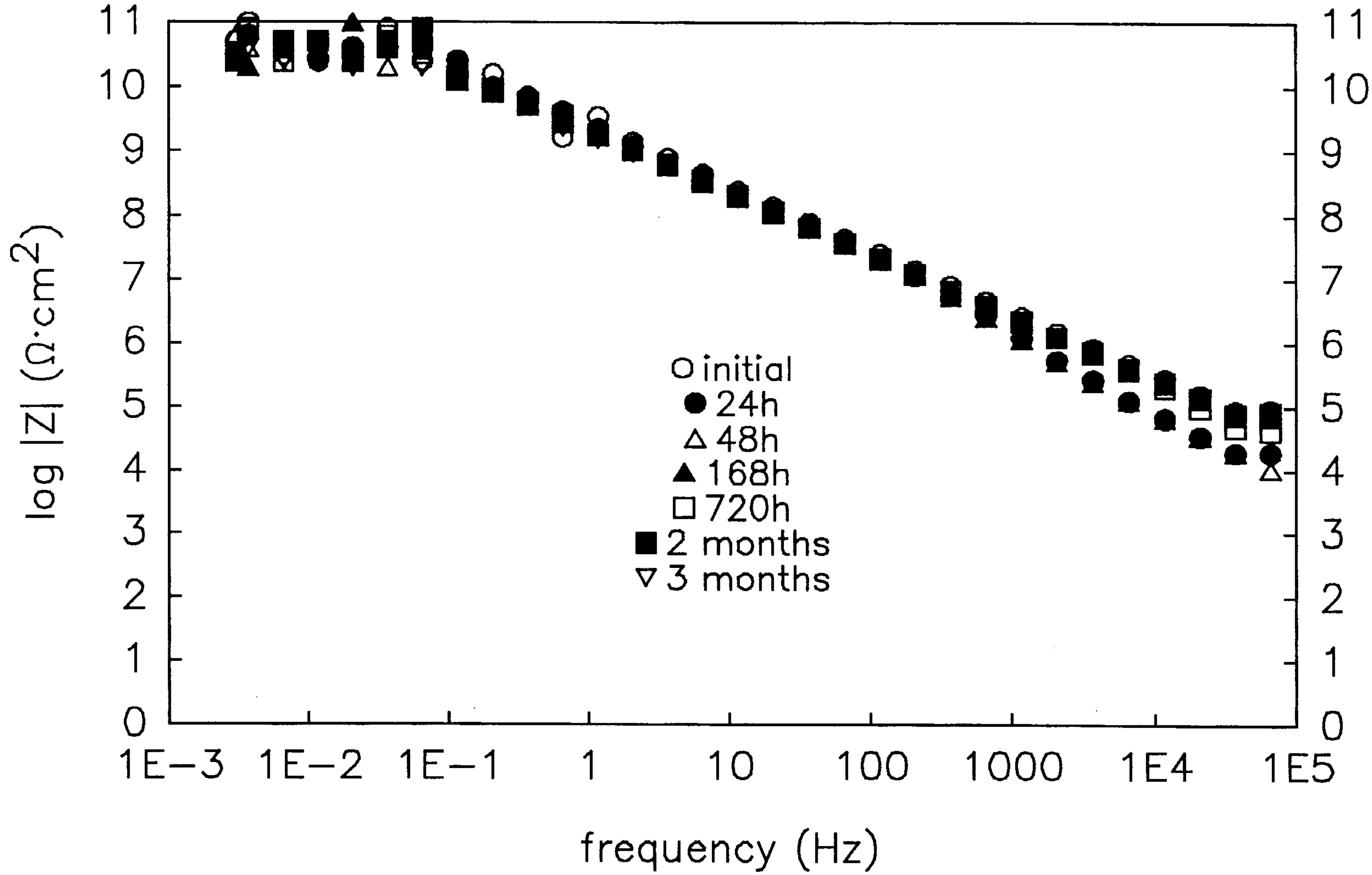

Figure 104. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 0.2 μm filter in ZnMoP saturated 0.01 M K_2SO_4.

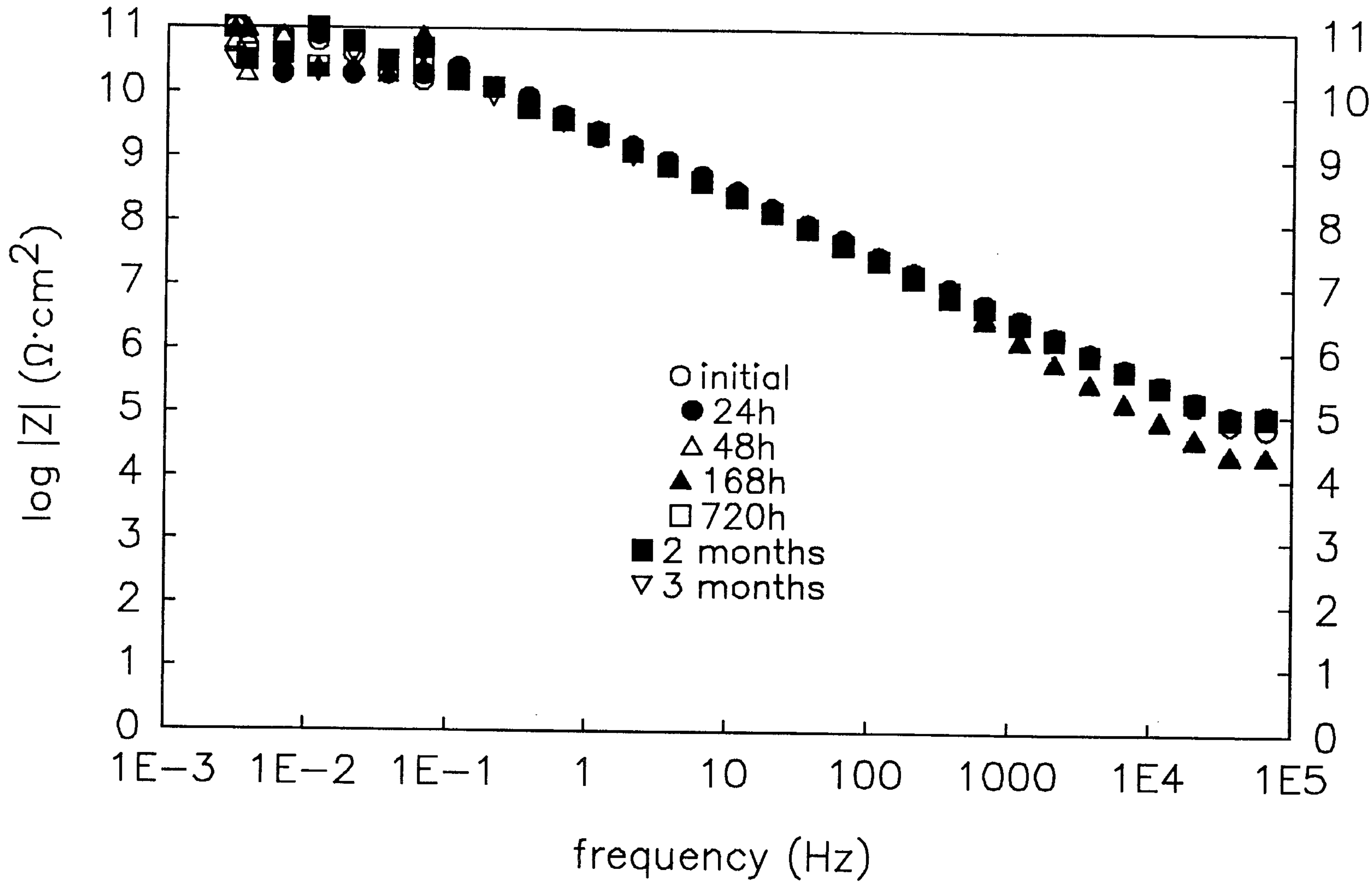

Figure 105. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 μm filter in ZnMoP saturated 0.01 M K_2SO_4.

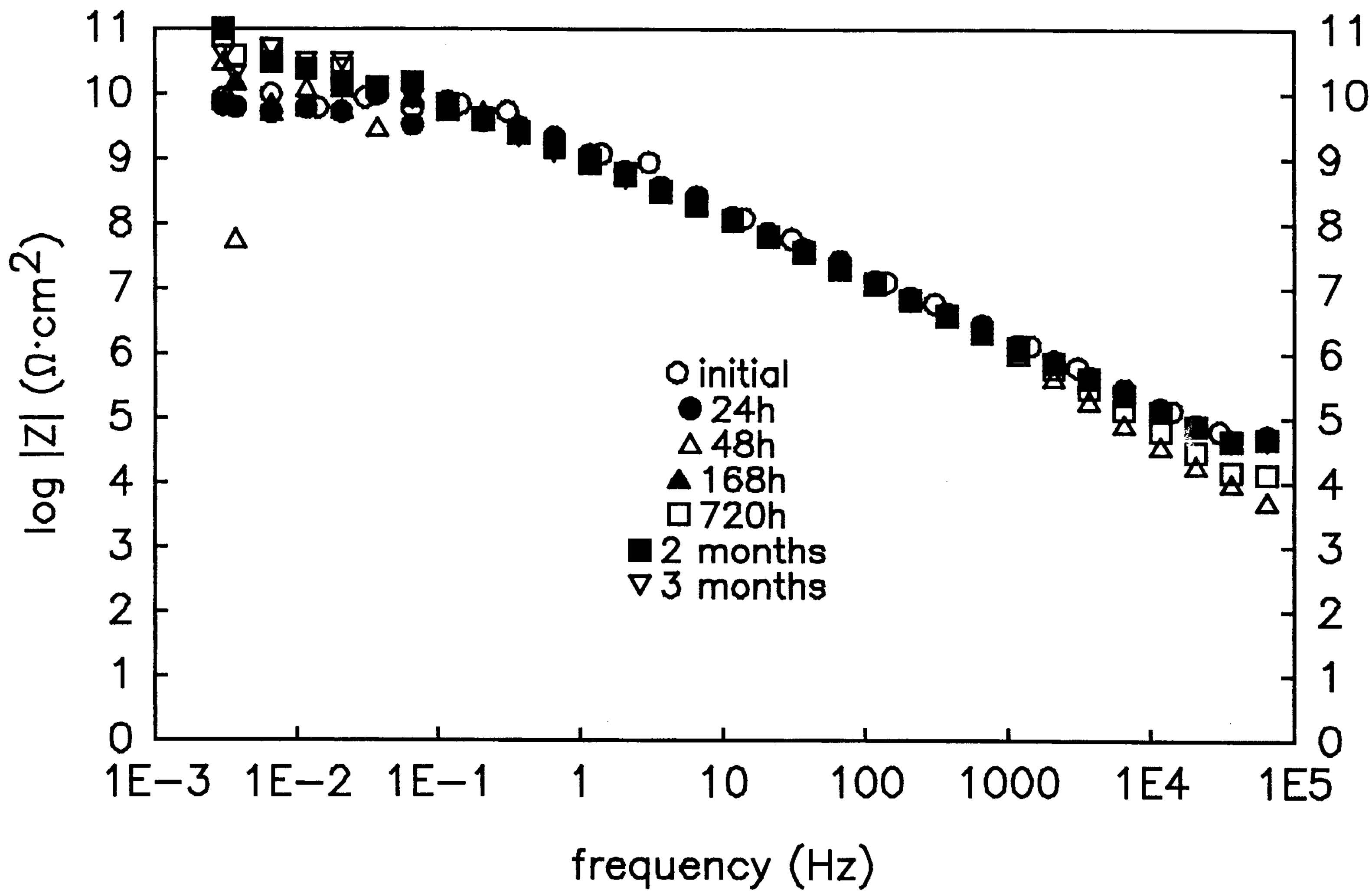

Figure 106. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in MoZnP saturated 0.01 M K_2SO_4.

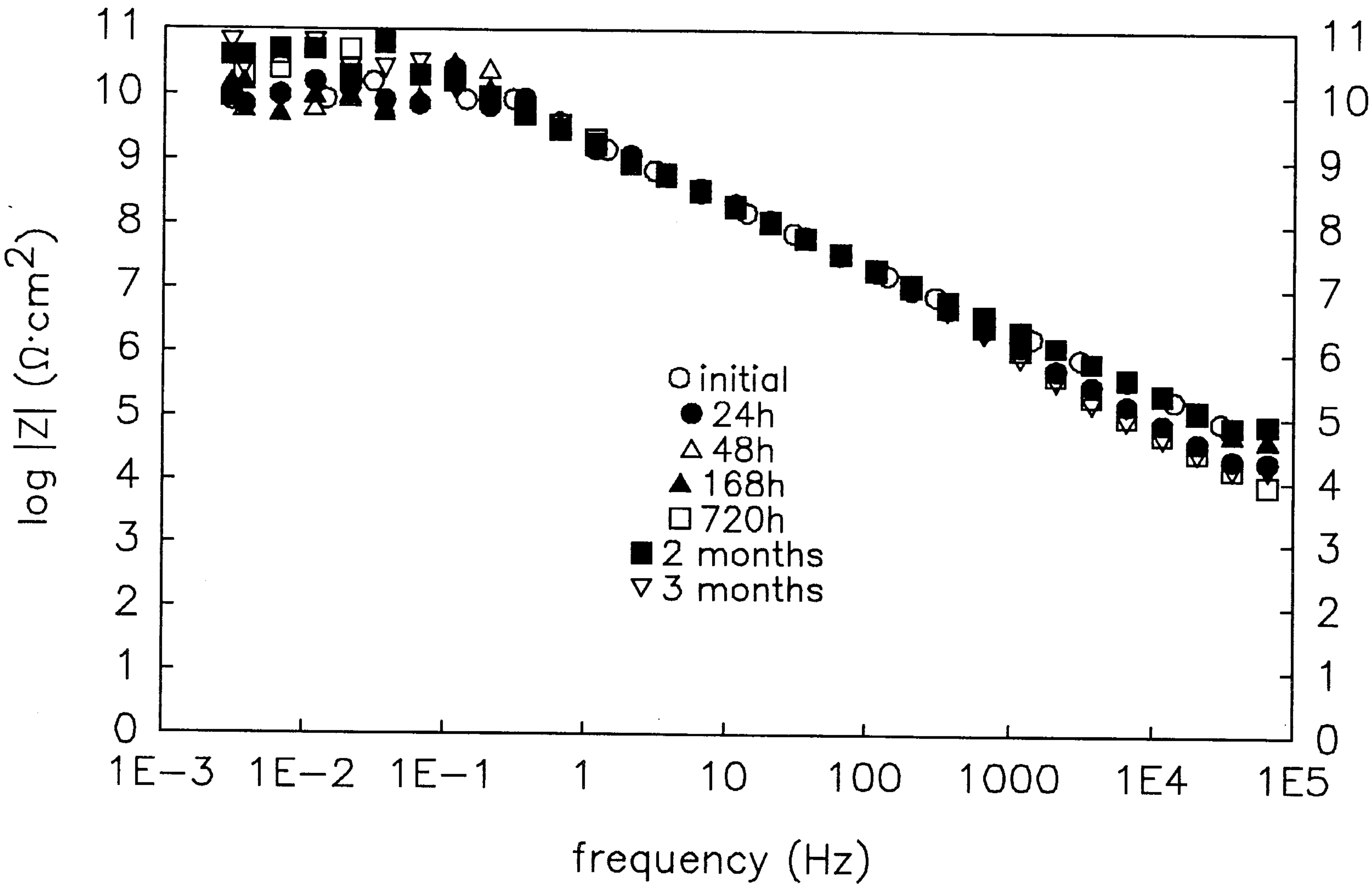

Figure 107. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 0.2 µm filter in MoZnP saturated 0.01 M K_2SO_4.

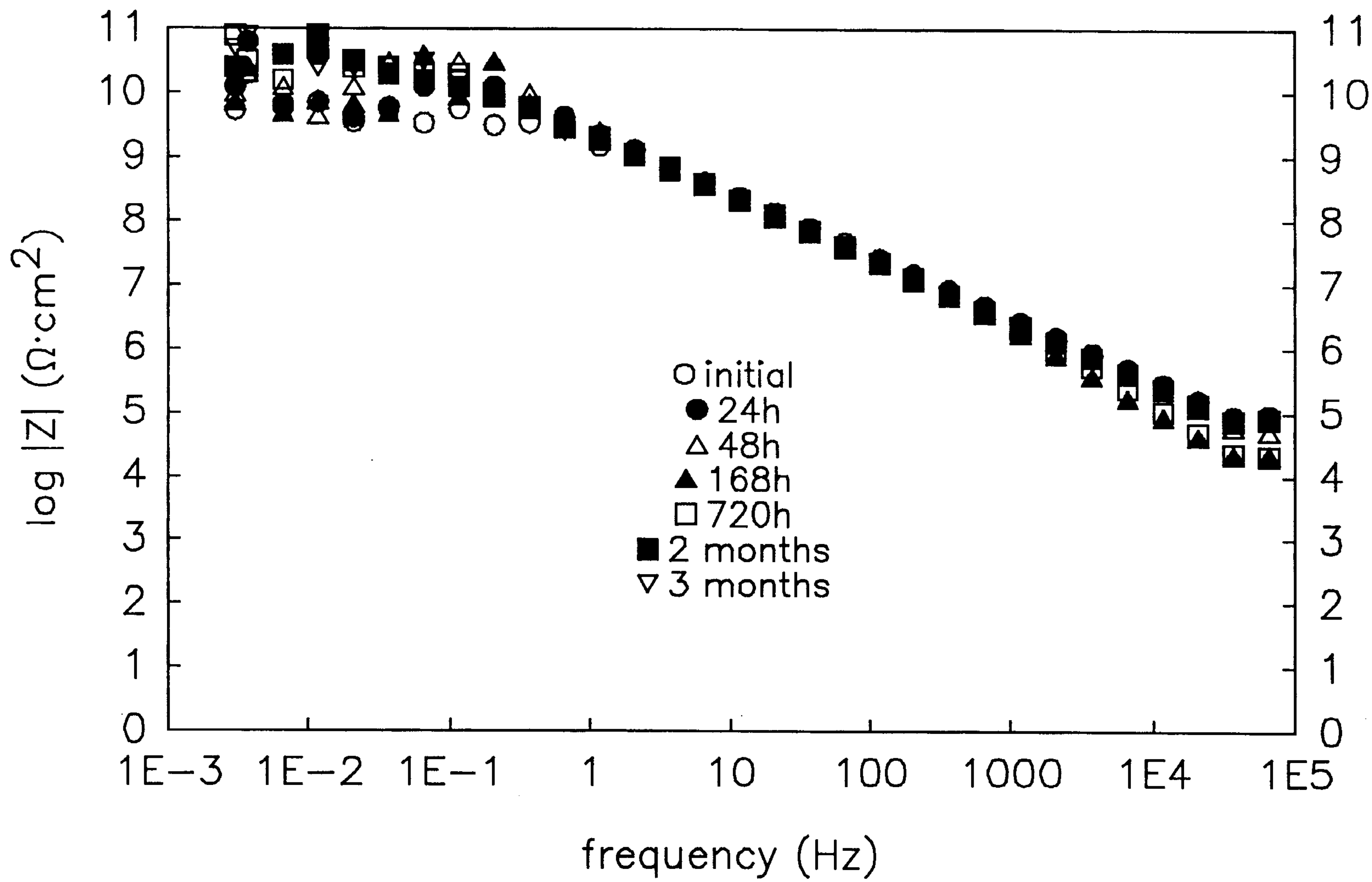

Figure 108. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 µm filter in MoZnP saturated 0.01 M K_2SO_4.

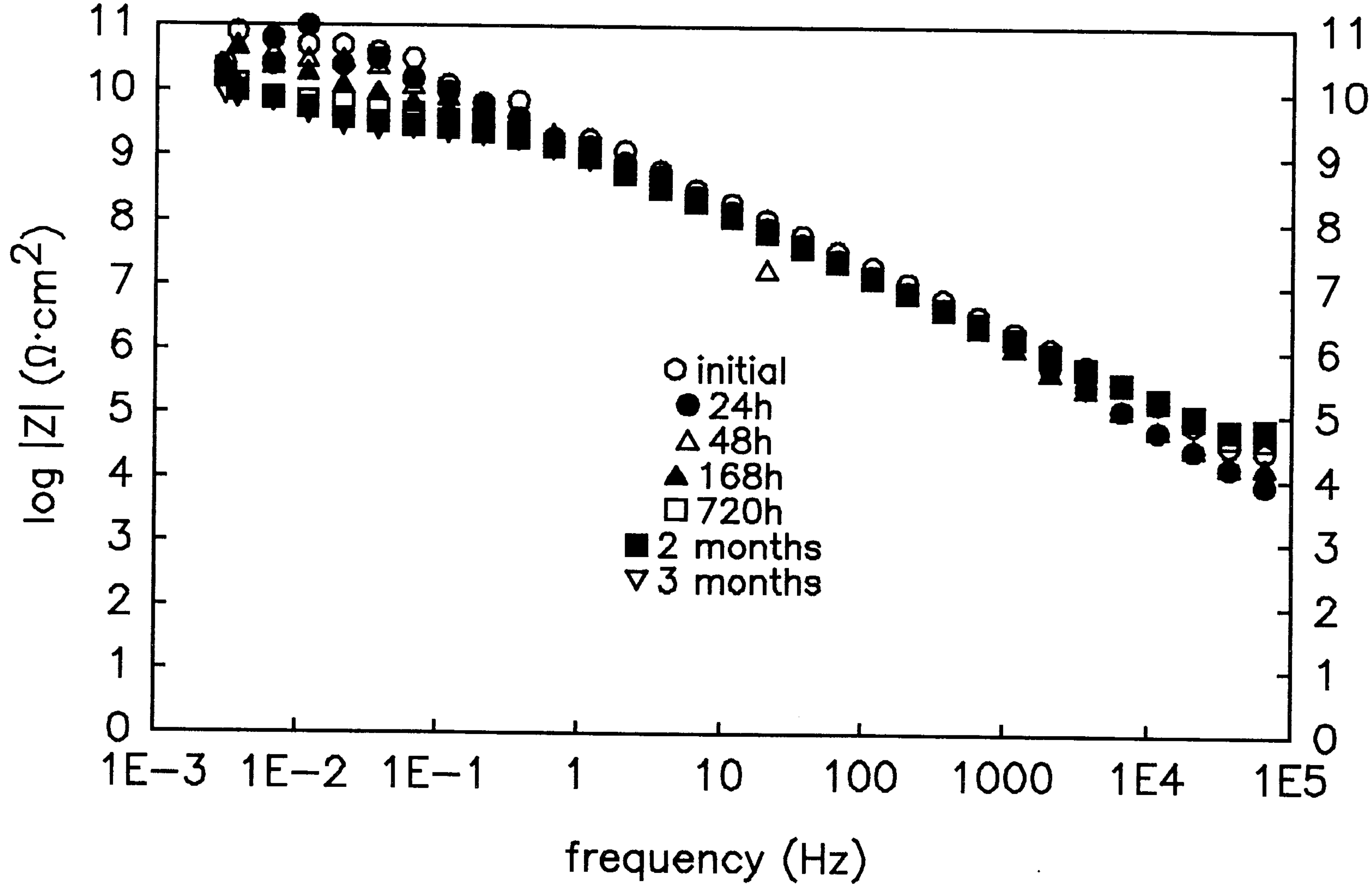

Figure 109. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al in ZnCin saturated 0.01 M K_2SO_4.

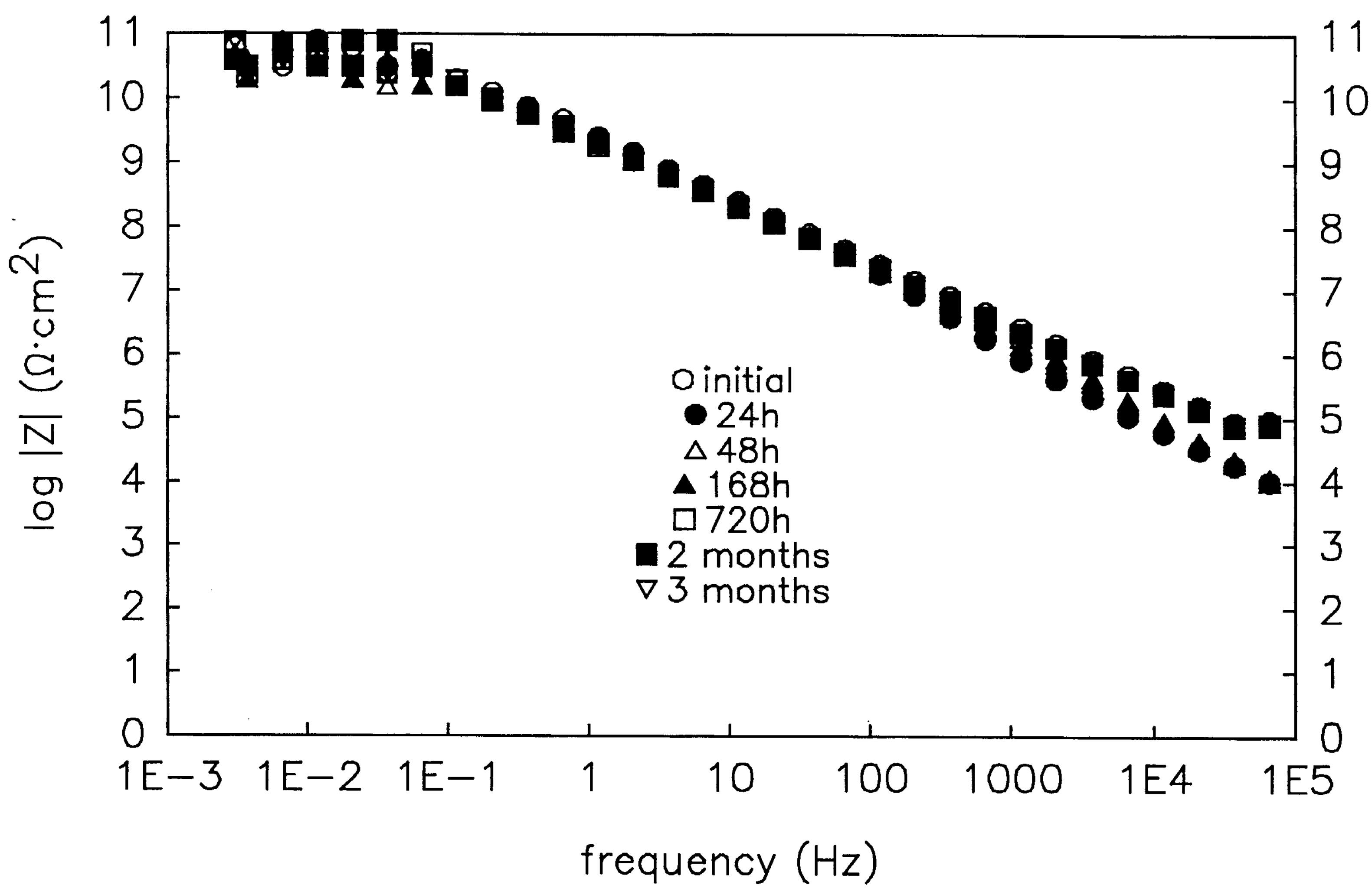

Figure 110. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 0.2 μm filter in ZnCin saturated 0.01 M K_2SO_4.

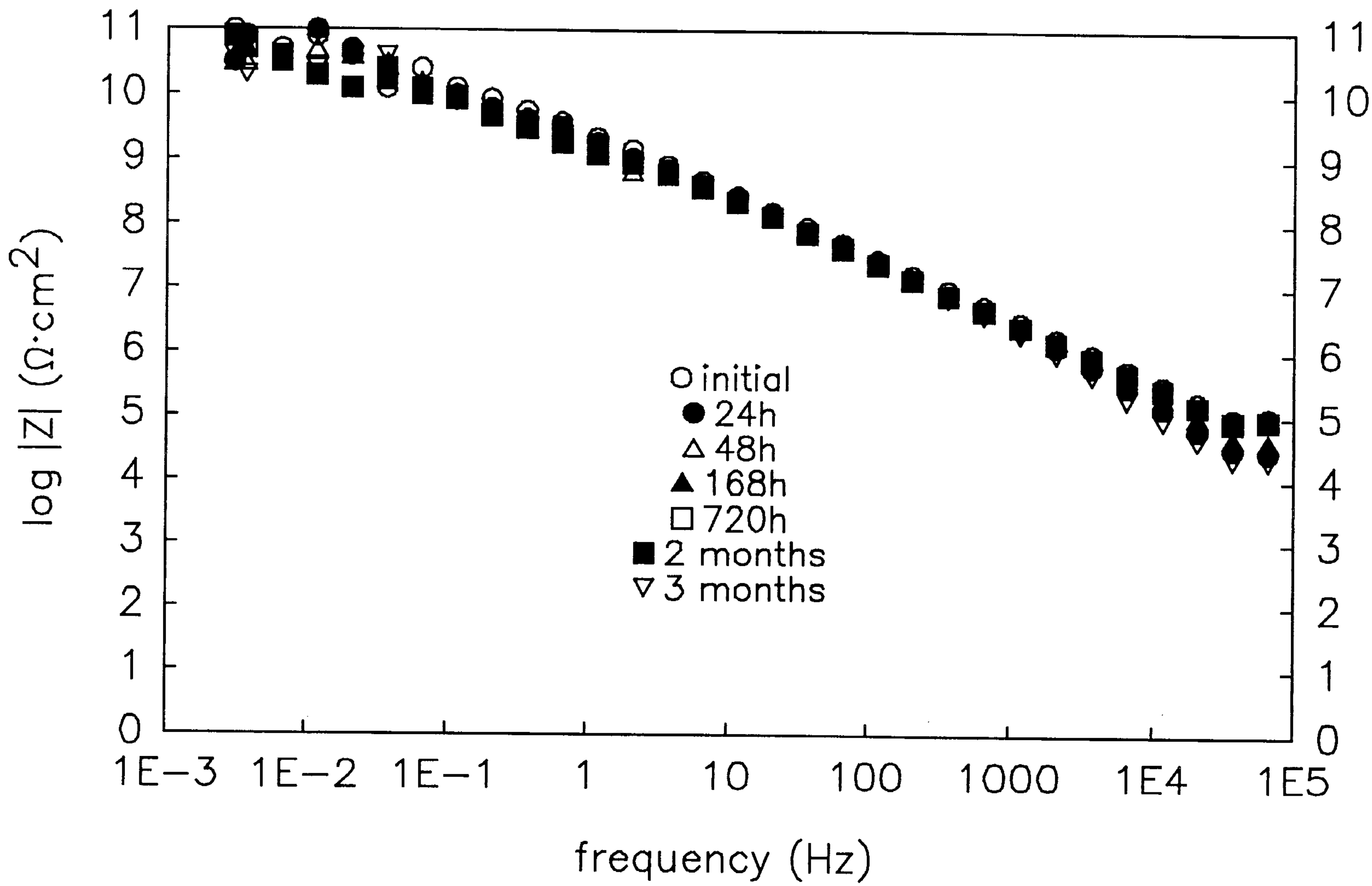

Figure 111. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with a 5.0 μm filter in ZnCin saturated 0.01 M K_2SO_4.

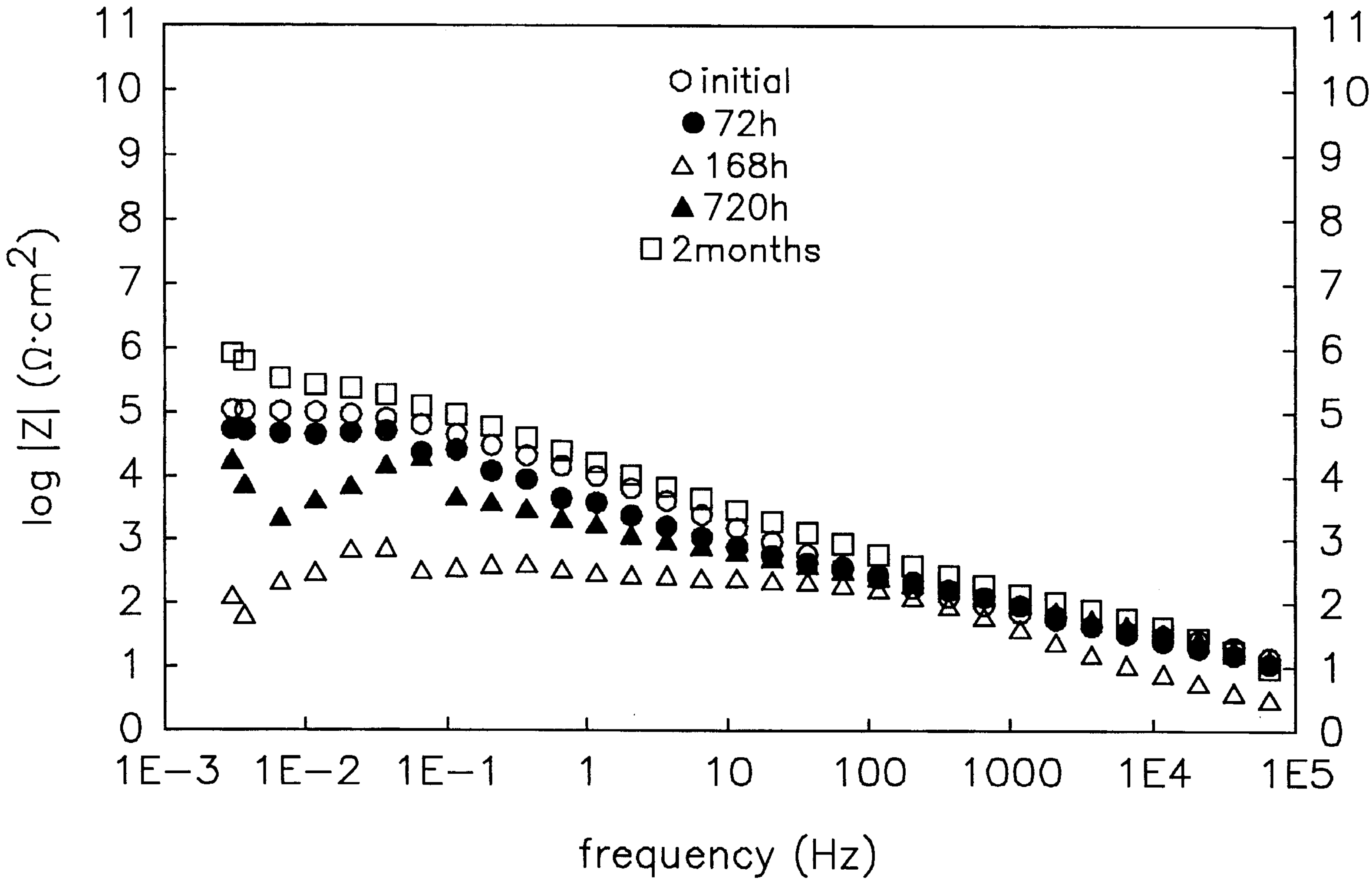

Figure 112. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 μm diameter defect in 0.01 M K_2SO_4.

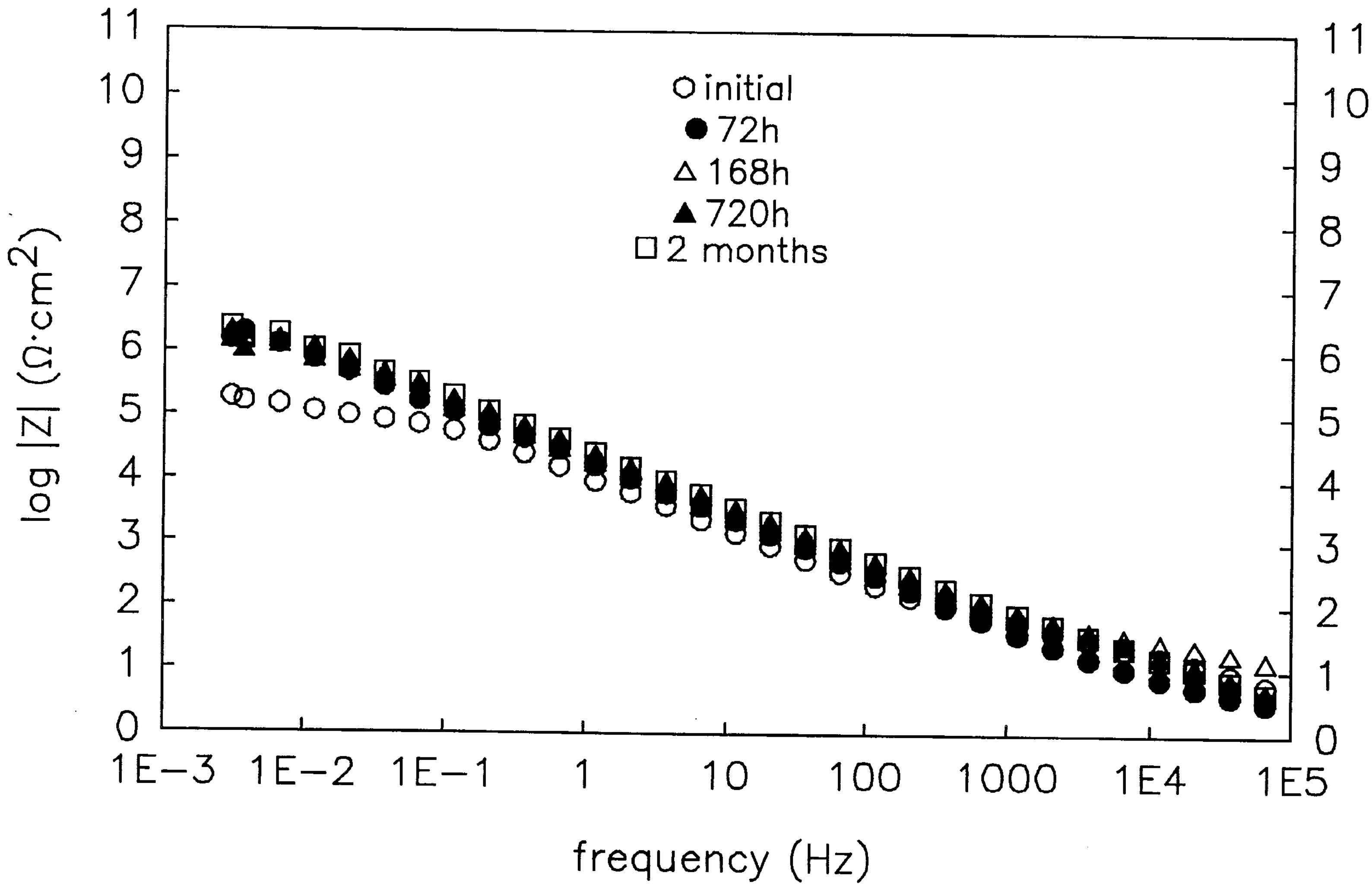

Figure 113. Impedance spectra of Epoxy 1 cured 7 d at RT on CCC Al with an 800 µm diameter defect in MPSi saturated 0.01 M K_2SO_4.

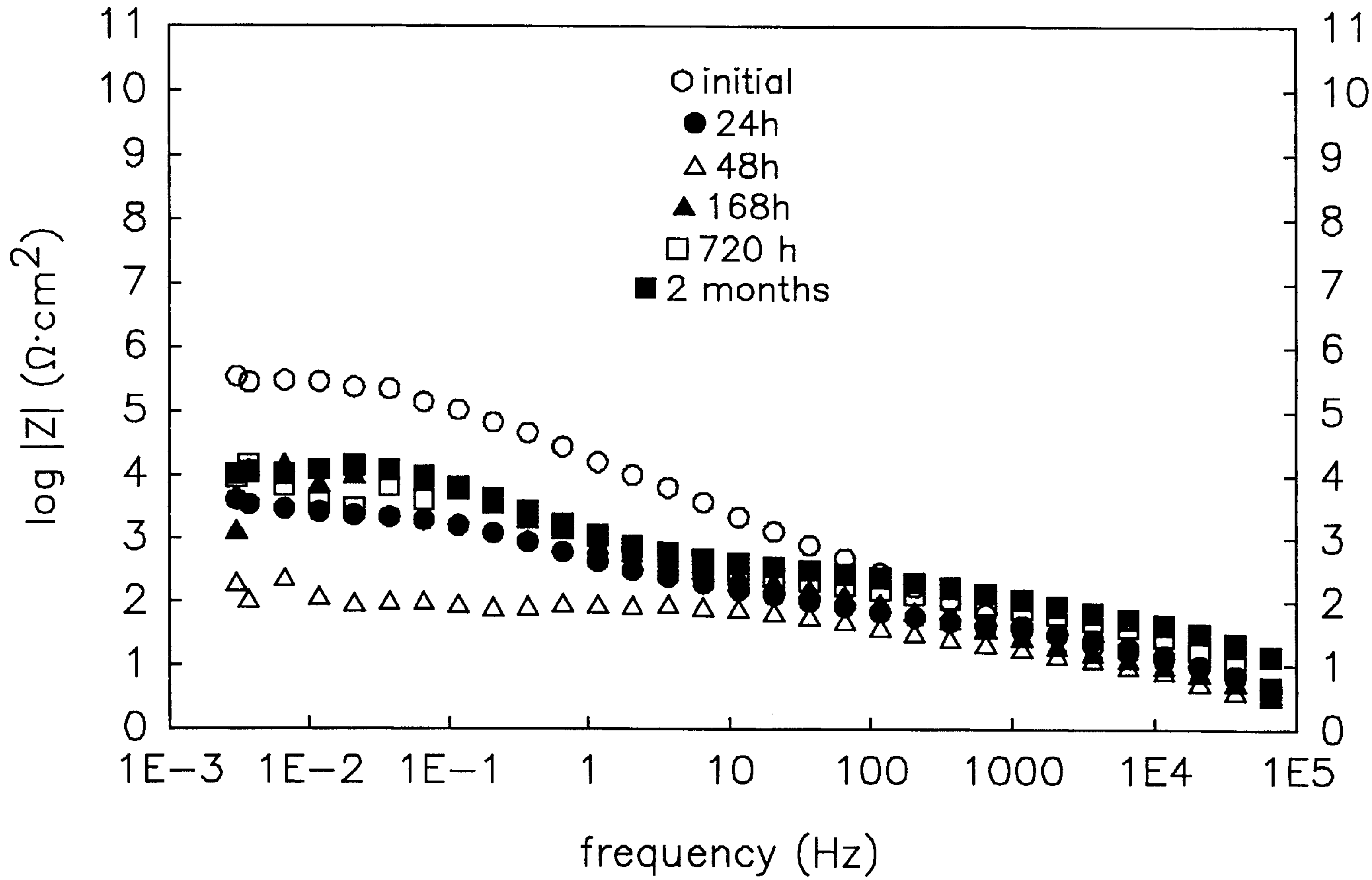

Figure 114. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 μm diameter defect in CaPSi saturated 0.01 M K_2SO_4.

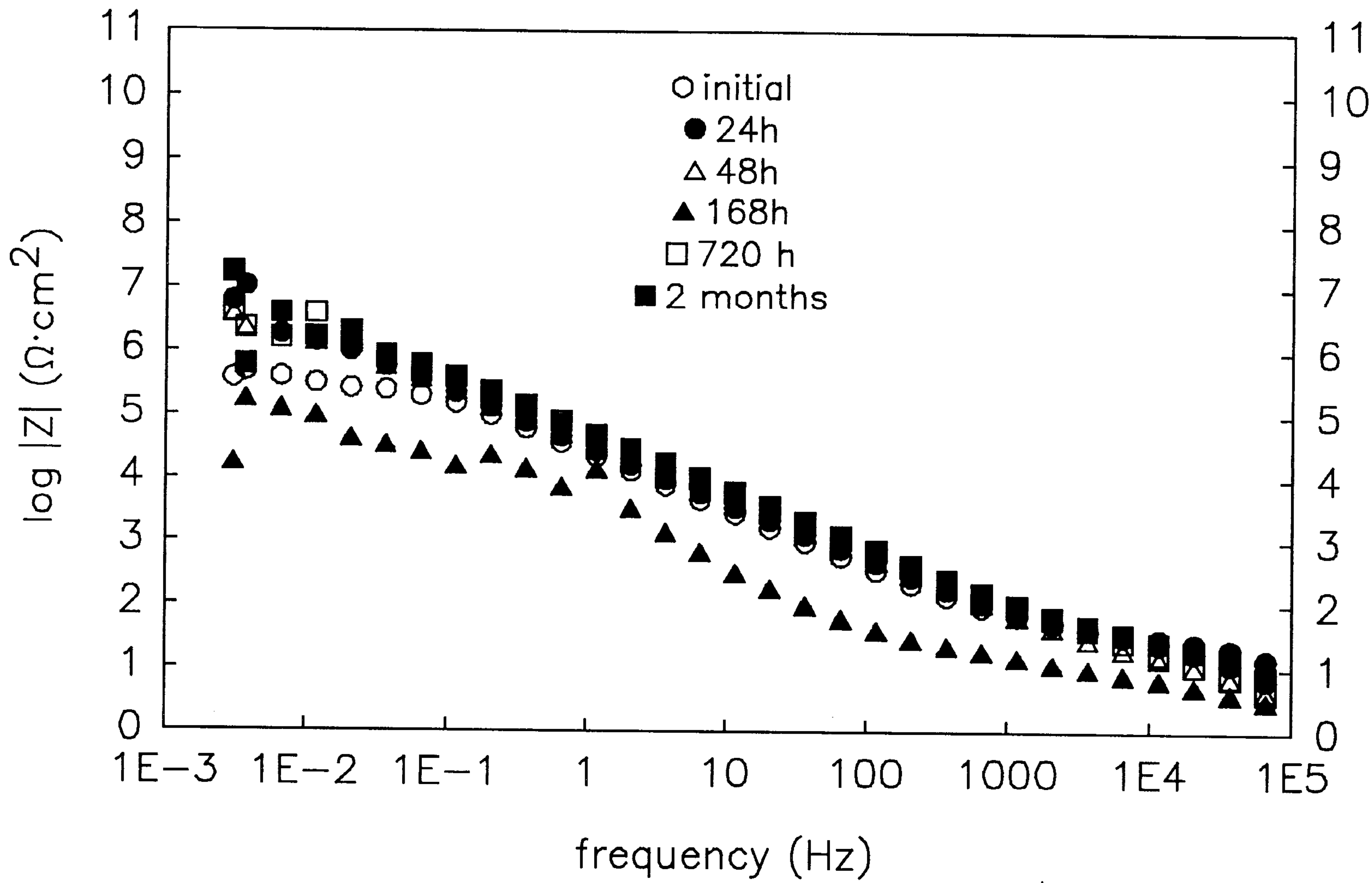

Figure 115. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 μm diameter defect in BaBor saturated 0.01 M K_2SO_4.

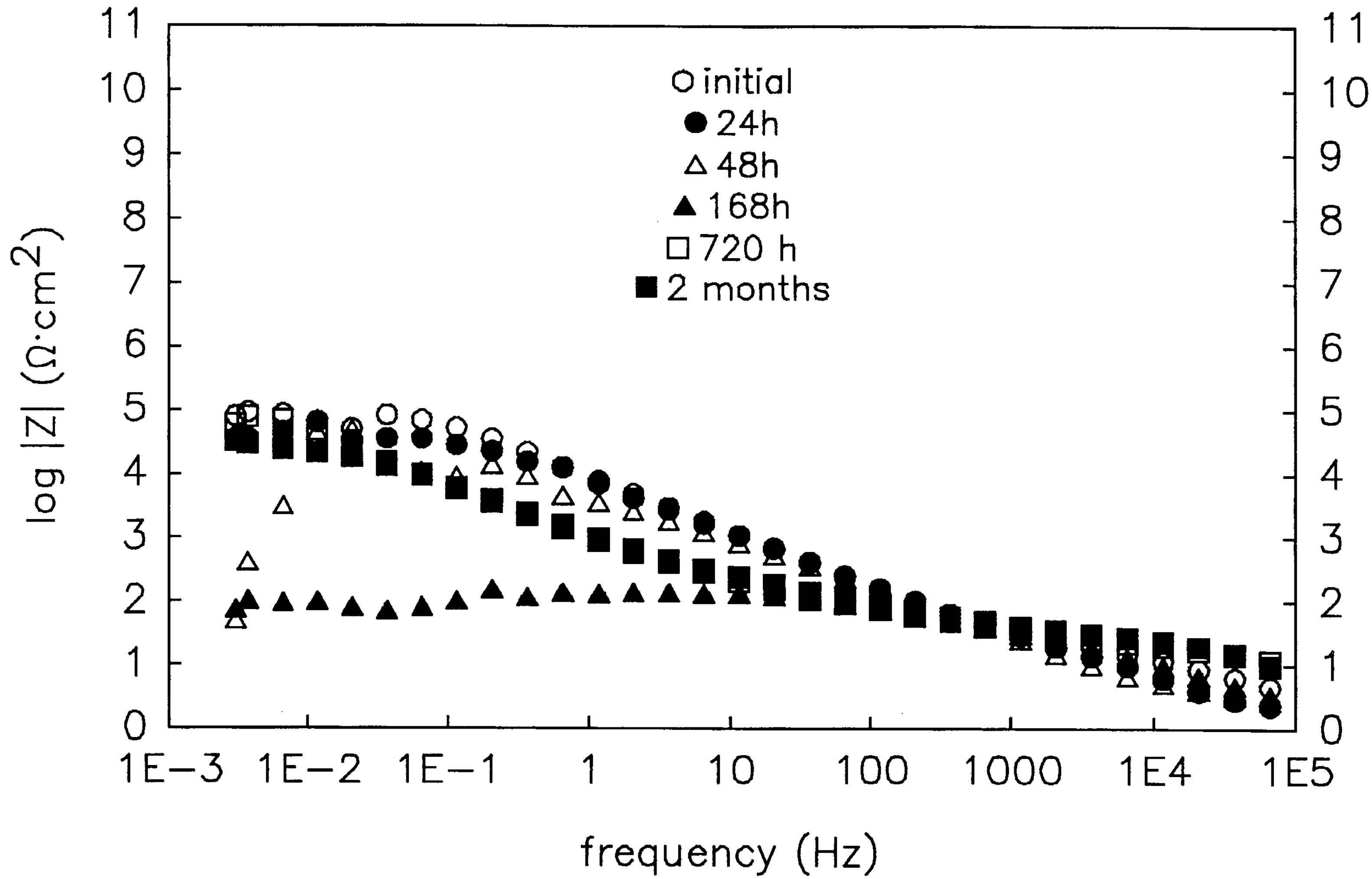

Figure 116. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 µm diameter defect in ZnMoP saturated 0.01 M K_2SO_4.

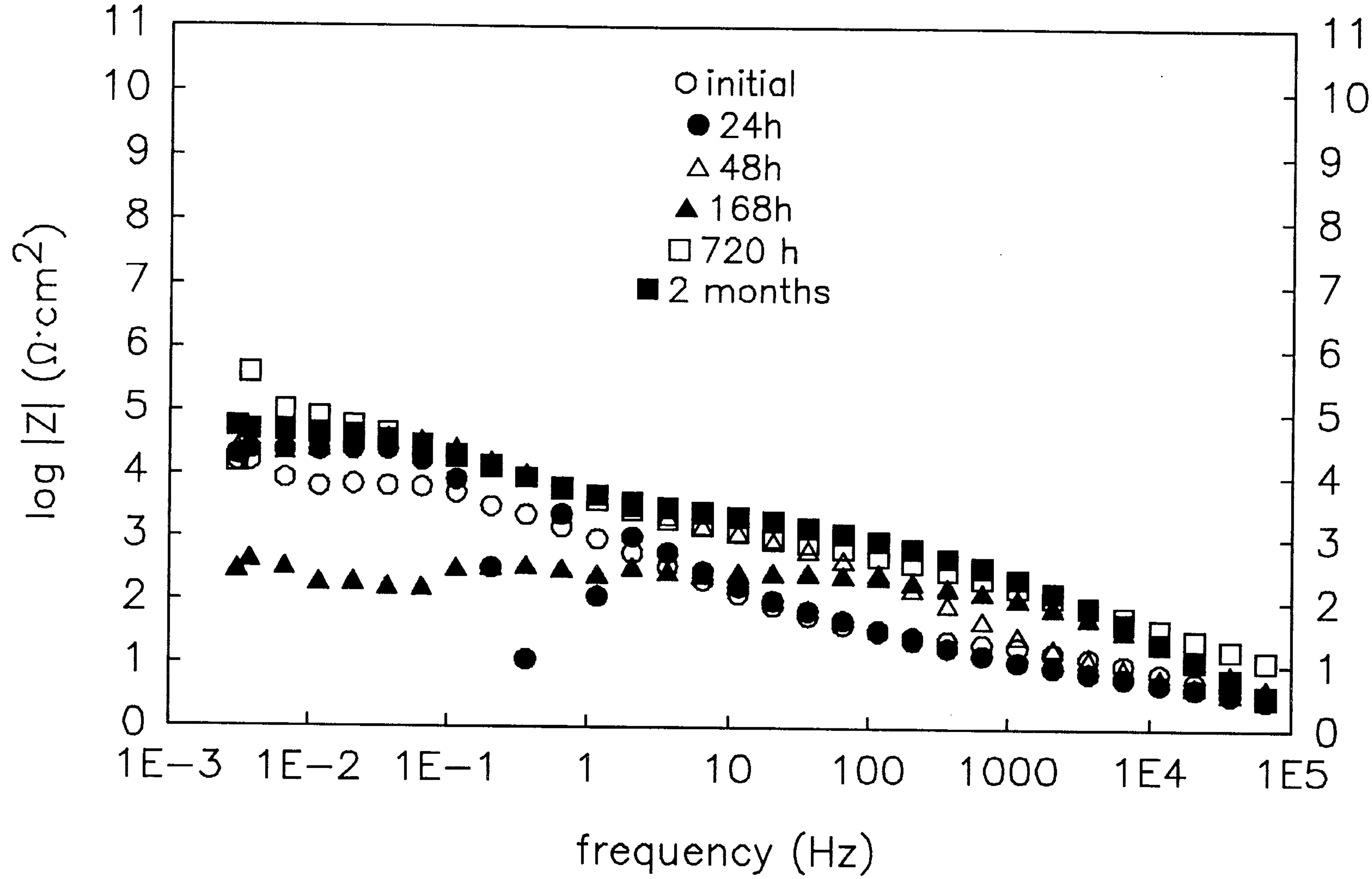

Figure 117. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 μm diameter defect in ZnAlP saturated 0.01 M K_2SO_4.

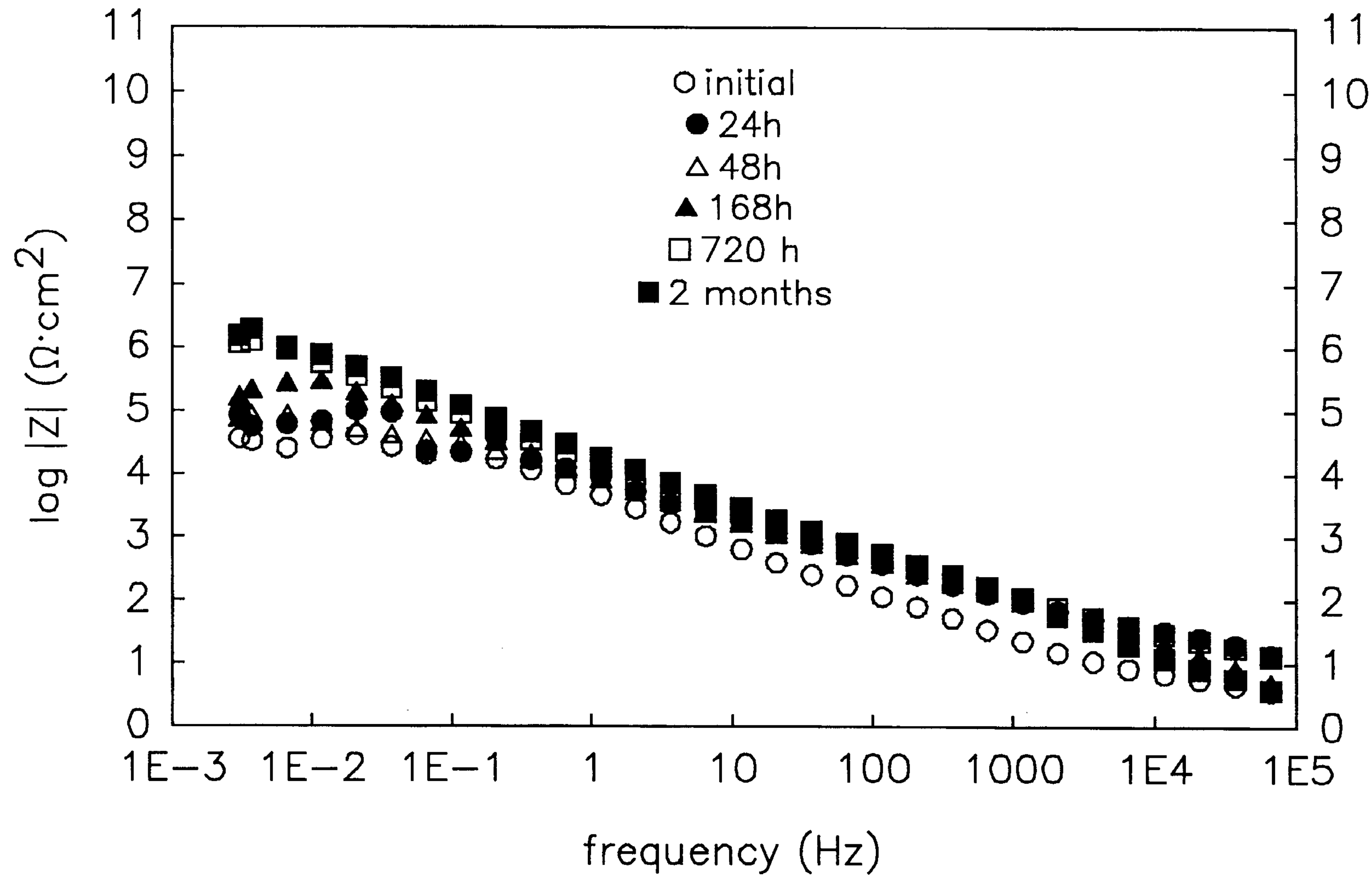

Figure 118. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 μm diameter defect in M1PSi saturated 0.01 M K_2SO_4.

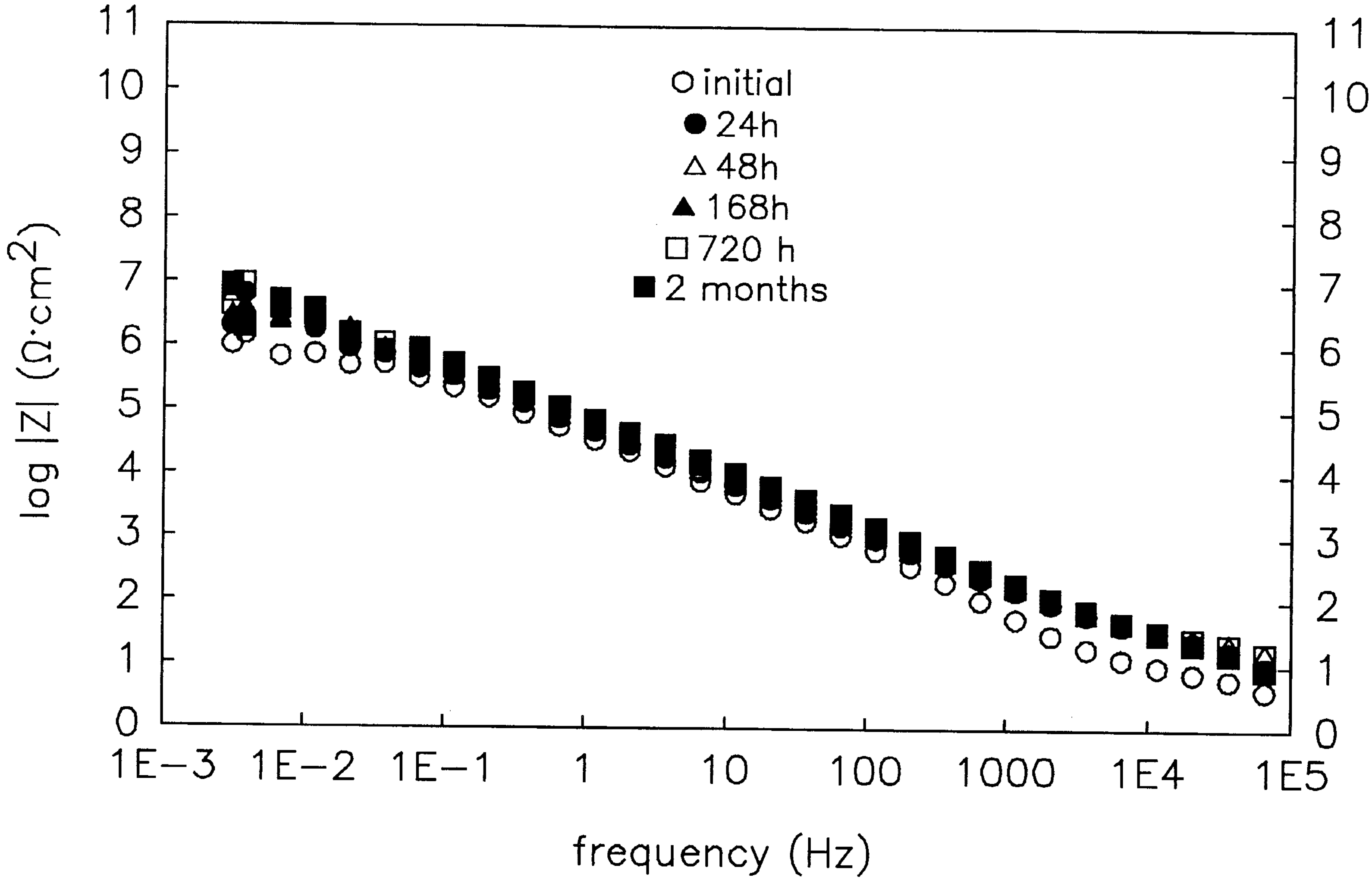

Figure 119. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 μm diameter defect in CaSi saturated 0.01 M K_2SO_4.

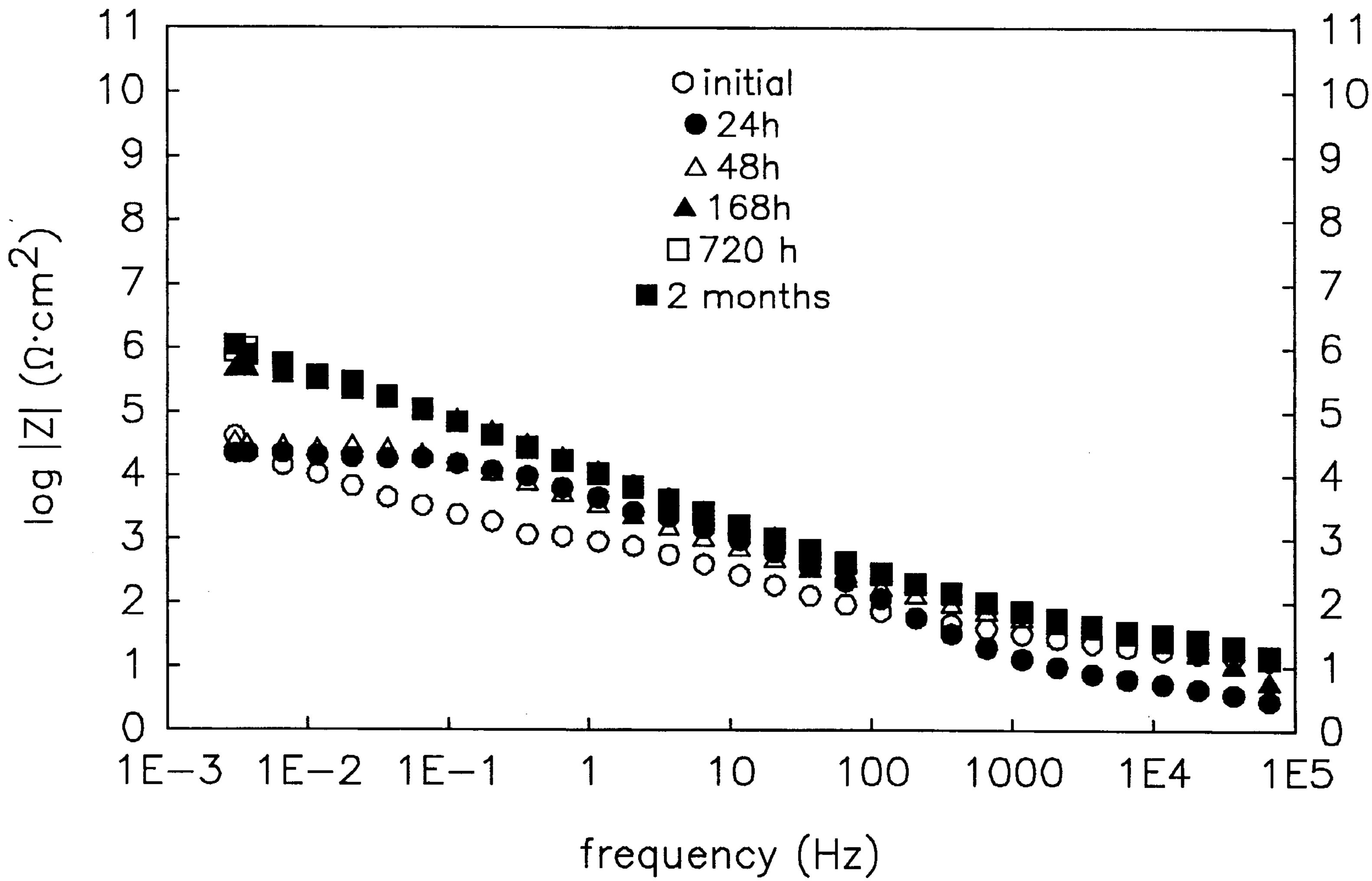

Figure 120. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 μm diameter defect in ZnMoP saturated 0.01 M K_2SO_4.

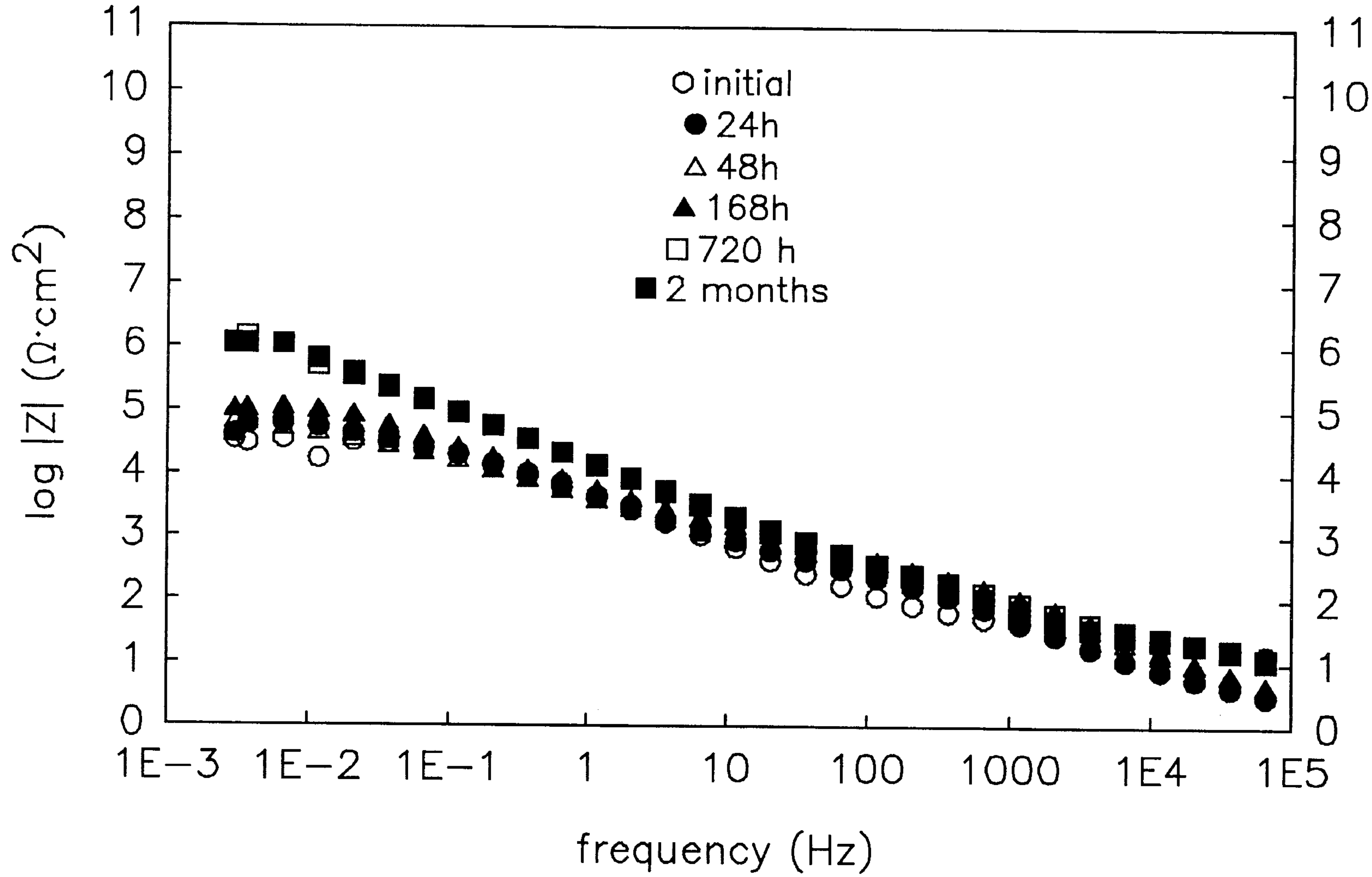

Figure 121. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 μm diameter defect in MoZnP saturated 0.01 M K_2SO_4.

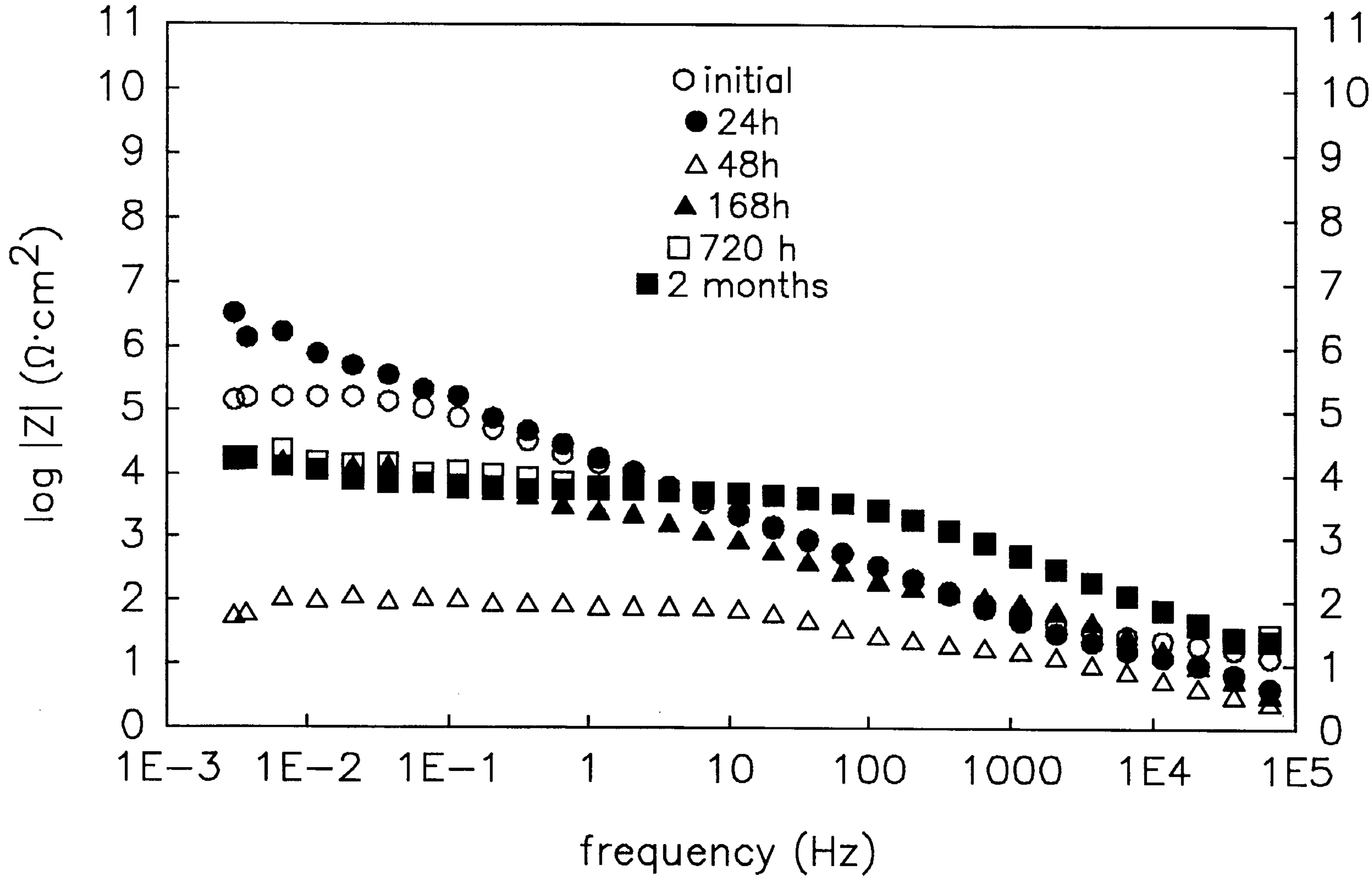

Figure 122. Impedance spectra of Epoxy 1 cured 7 days at RT on CCC Al with an 800 μm diameter defect in ZnCin saturated 0.01 M K_2SO_4.

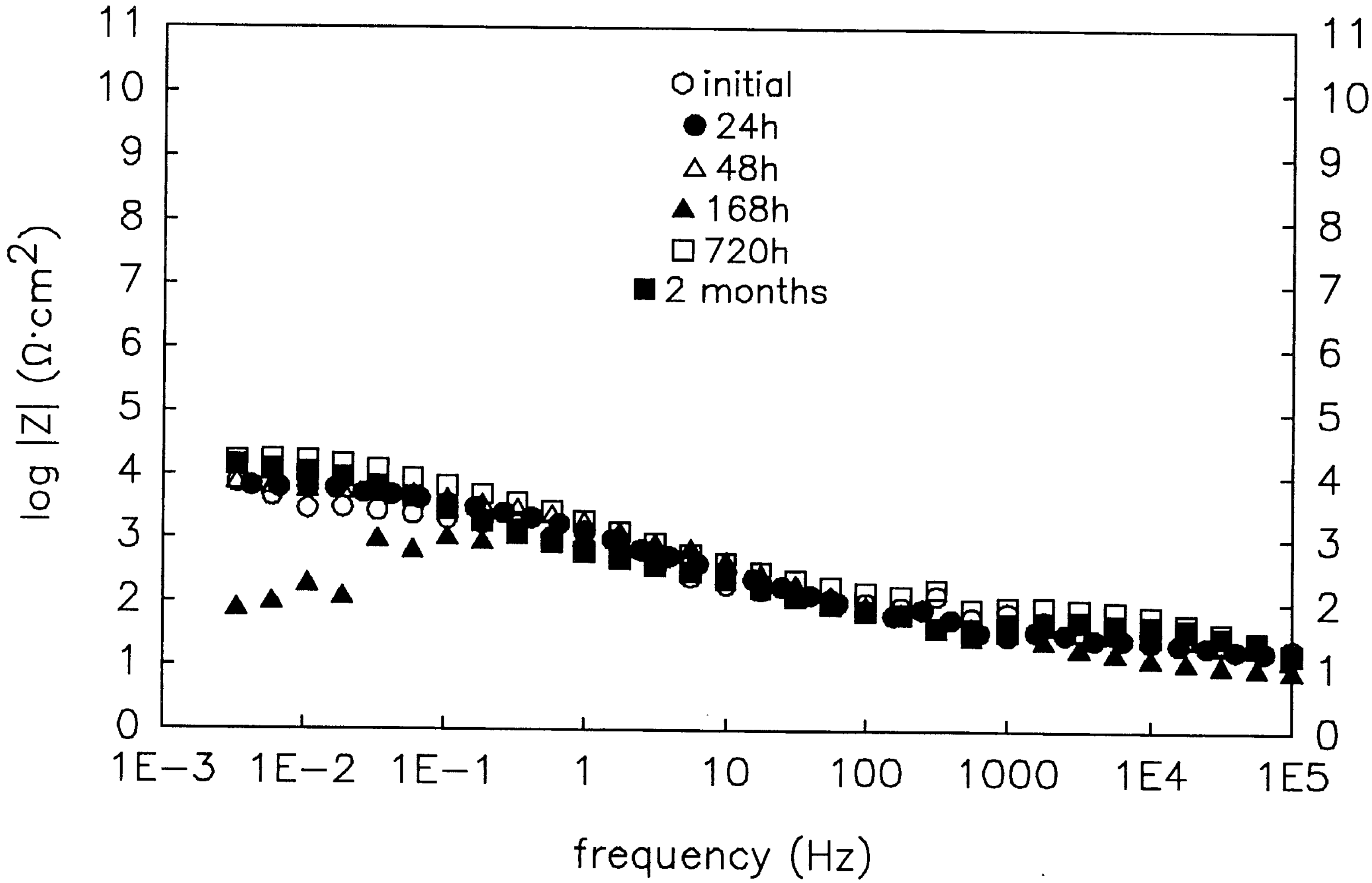

Figure 123. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in 0.01 M K_2SO_4.

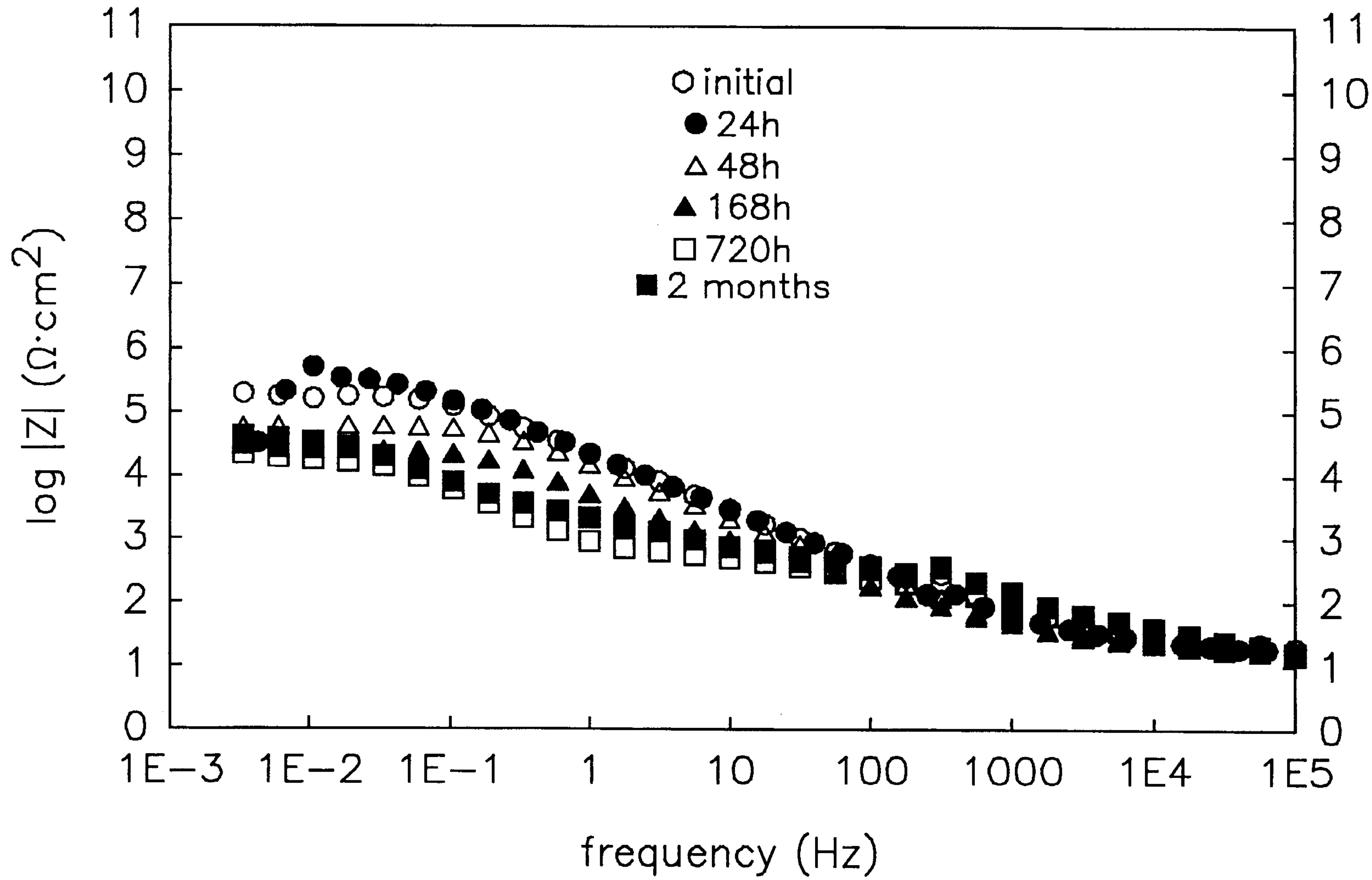

Figure 124. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in MPSi saturated 0.01 M K_2SO_4.

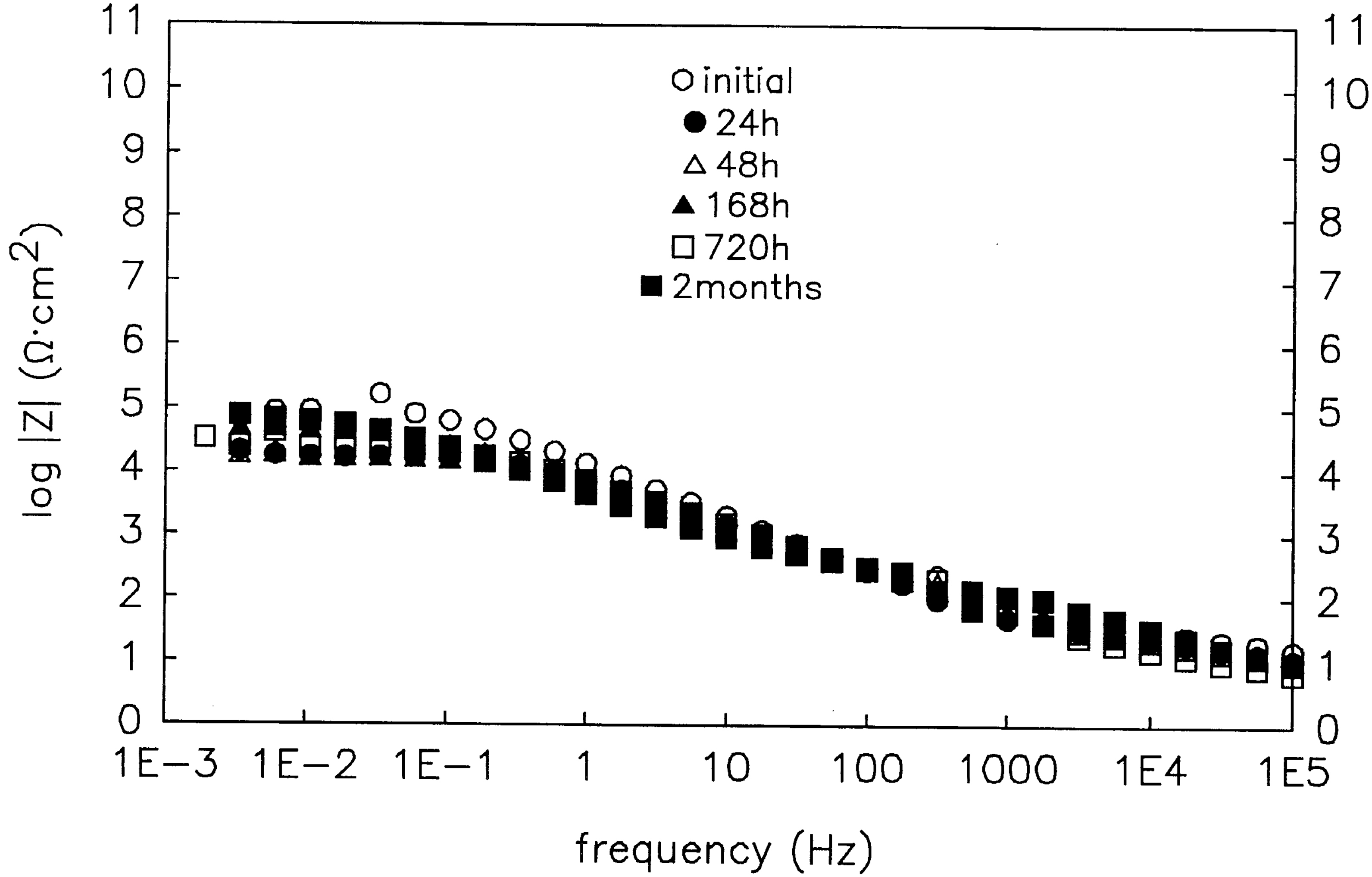

Figure 125. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in CaPSi saturated 0.01 M K_2SO_4.

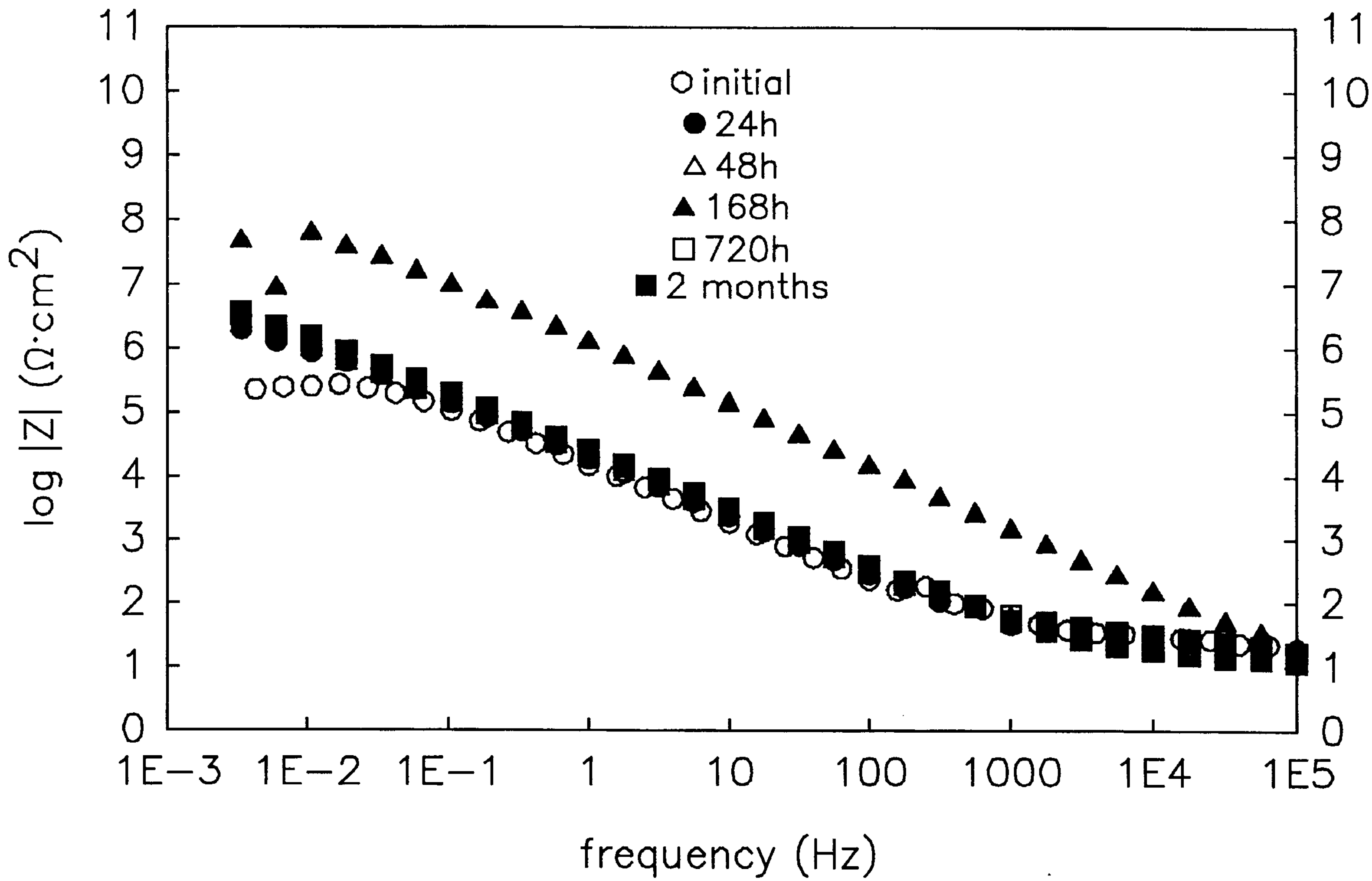

Figure 126. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in BaBor saturated 0.01 M K_2SO_4.

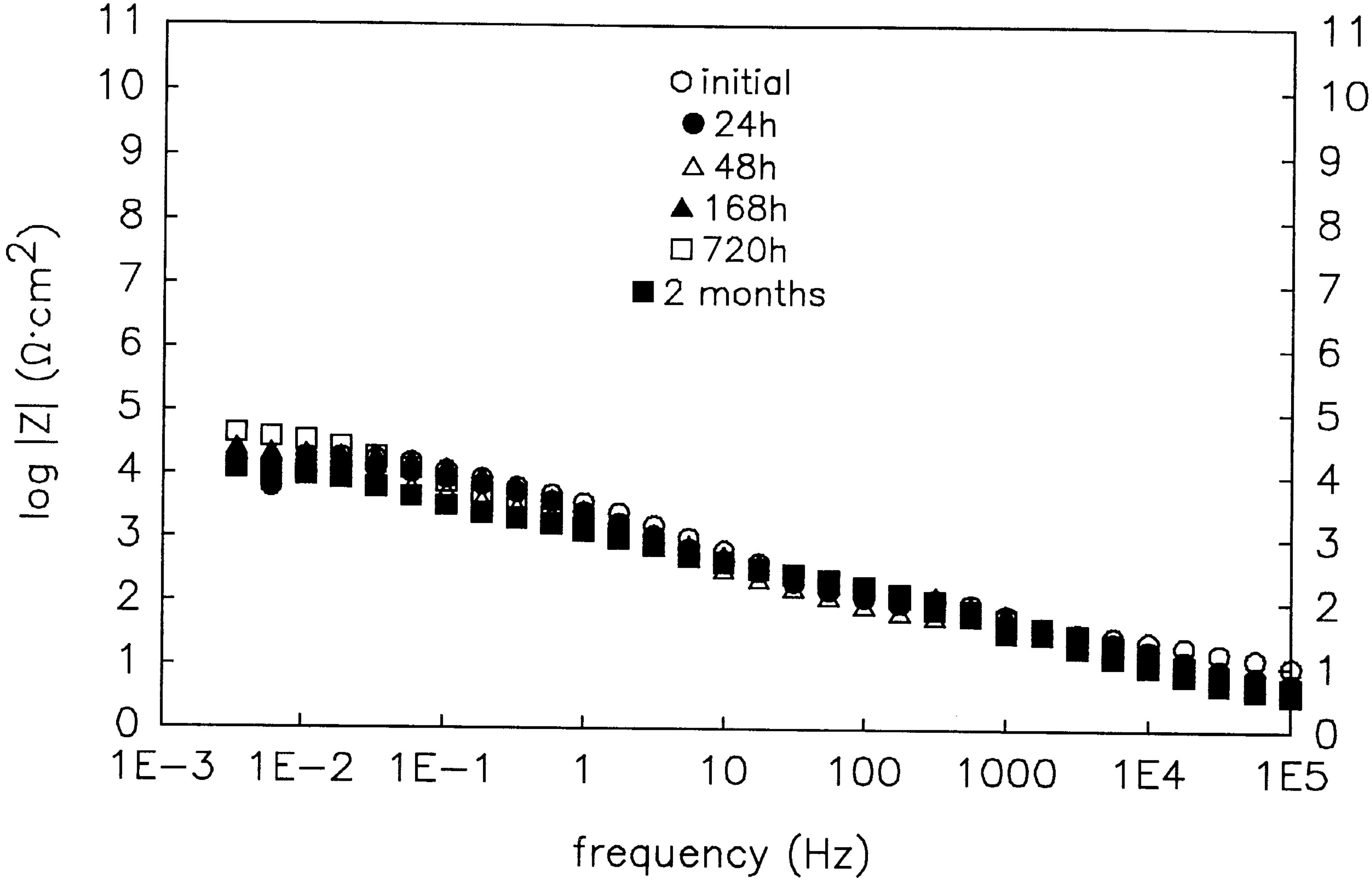

Figure 127. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in ZnoN saturated 0.01 M K_2SO_4.

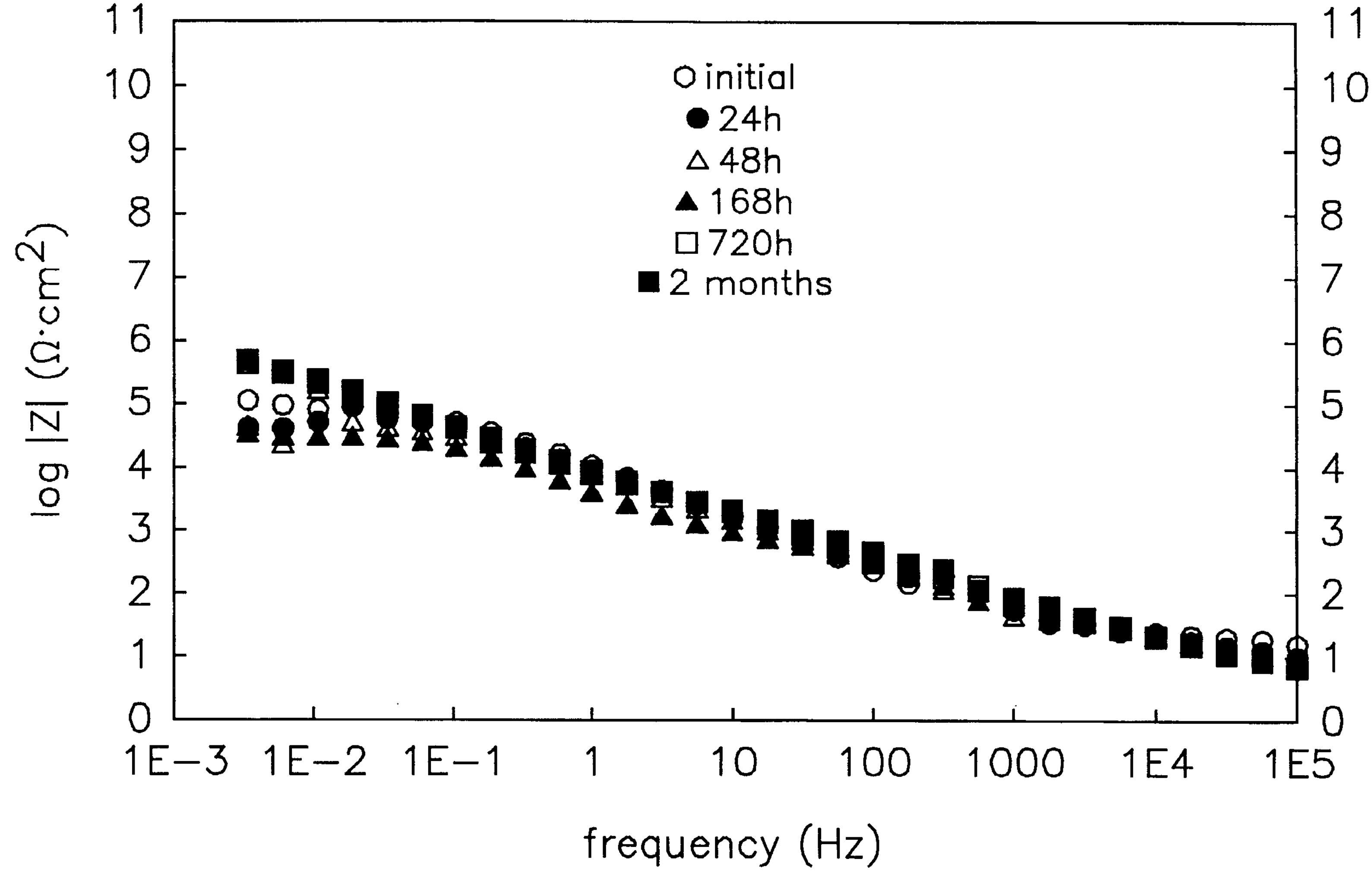

Figure 128. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in ZnAlP saturated 0.01 M K_2SO_4.

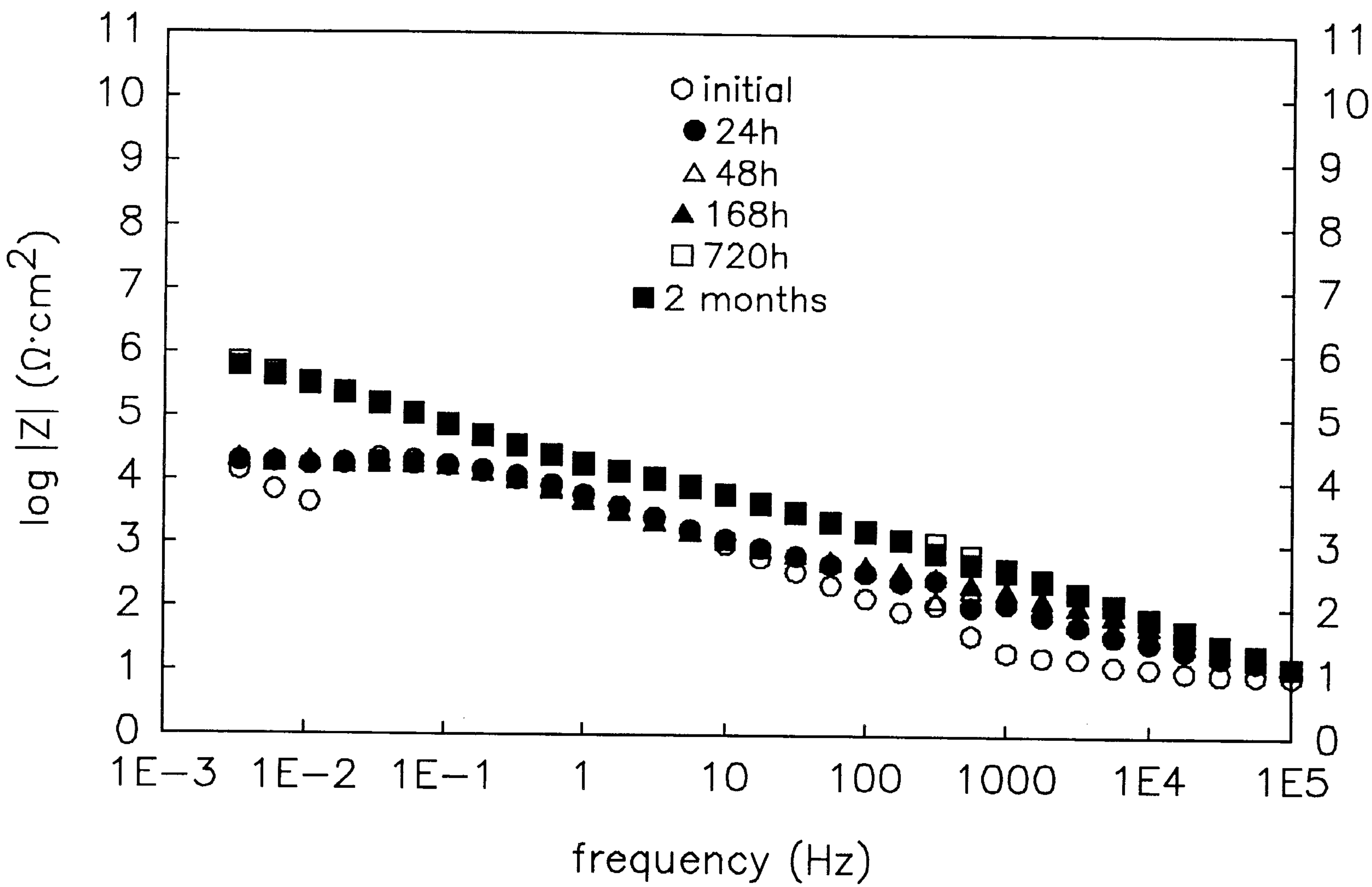

Figure 129. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in M1PSi saturated 0.01 M K_2SO_4.

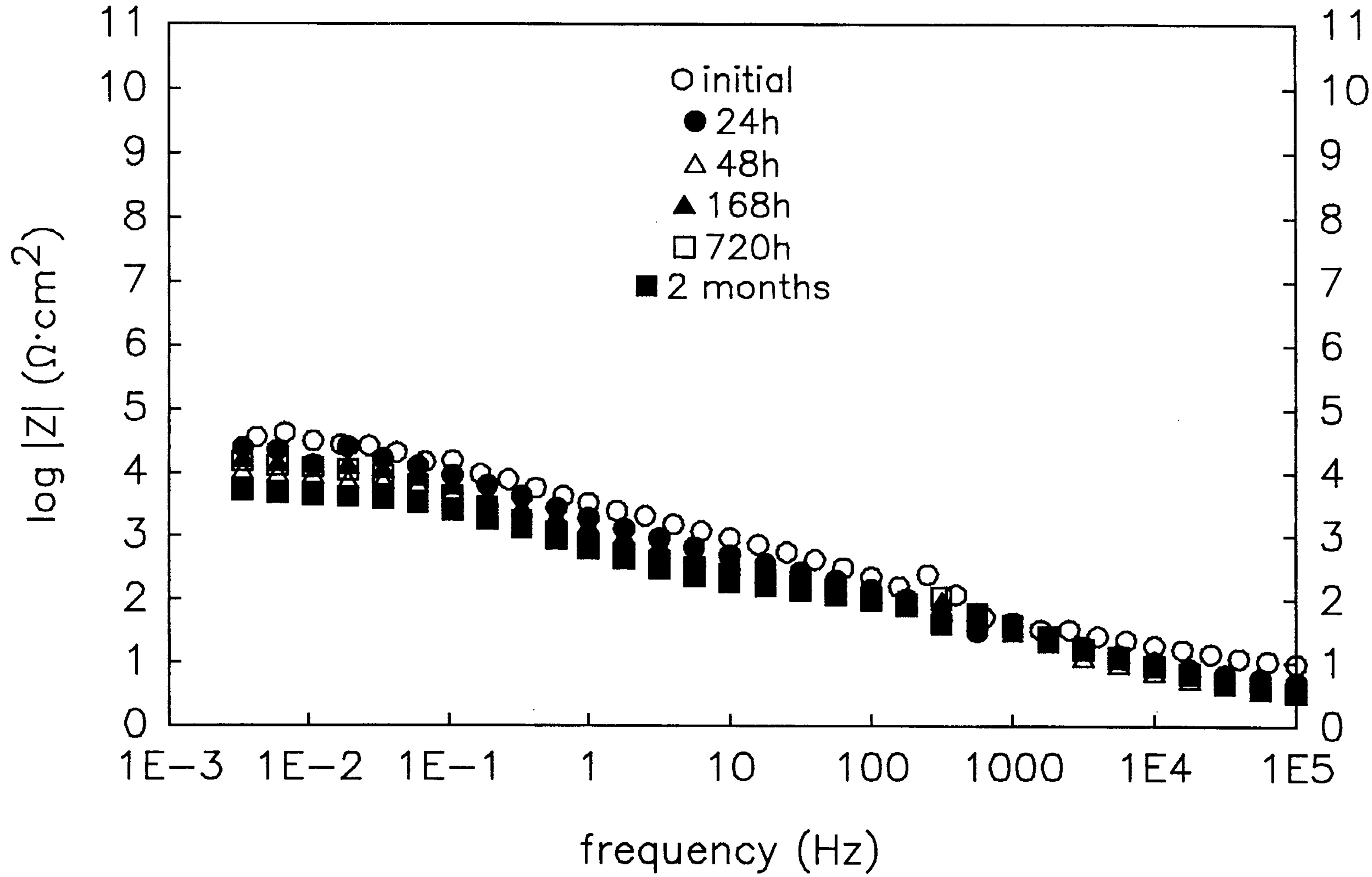

Figure 130. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in CaSi saturated 0.01 M K_2SO_4.

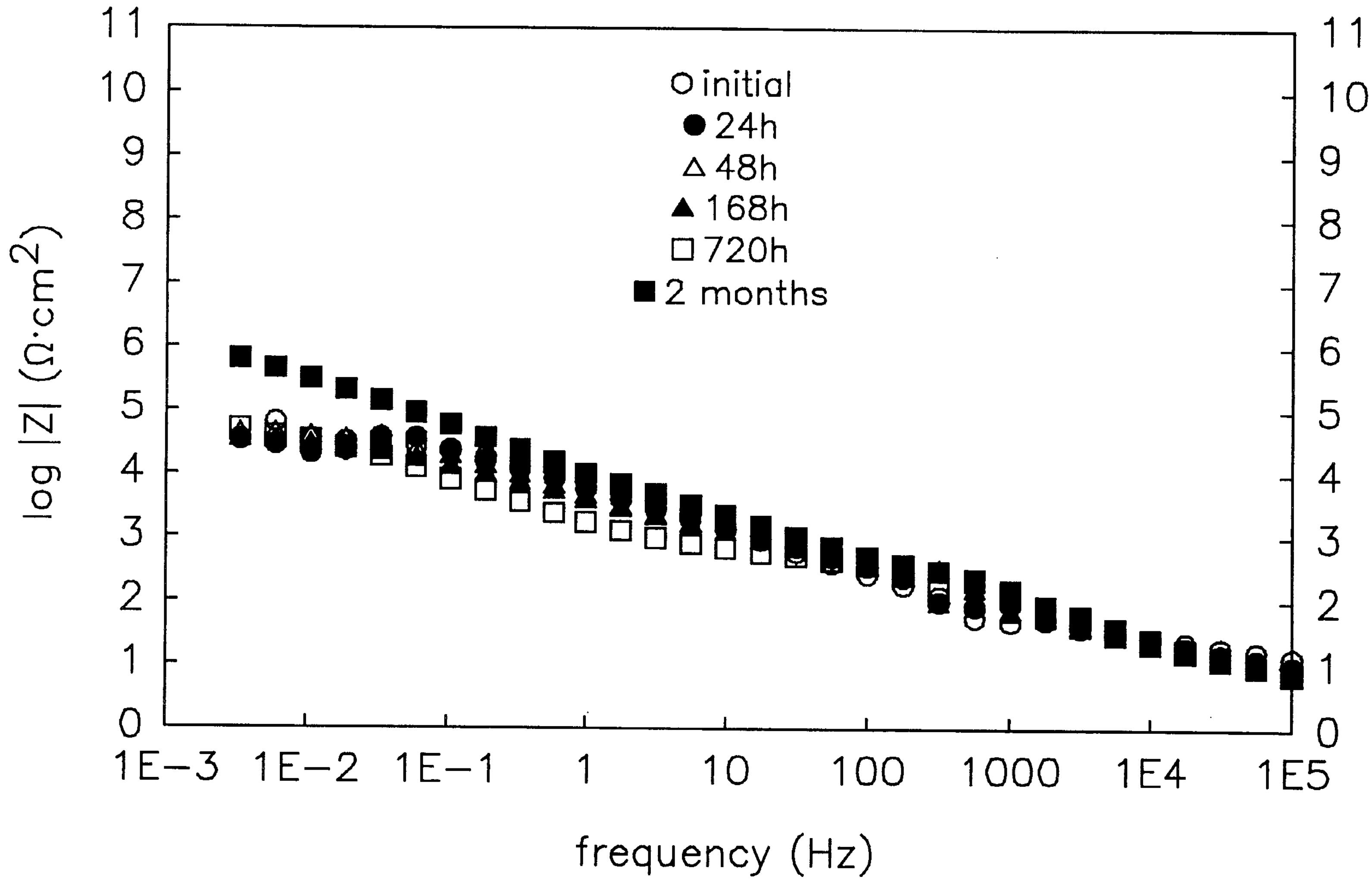

Figure 131. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 µm diameter defect in ZnMoP saturated 0.01 M K_2SO_4.

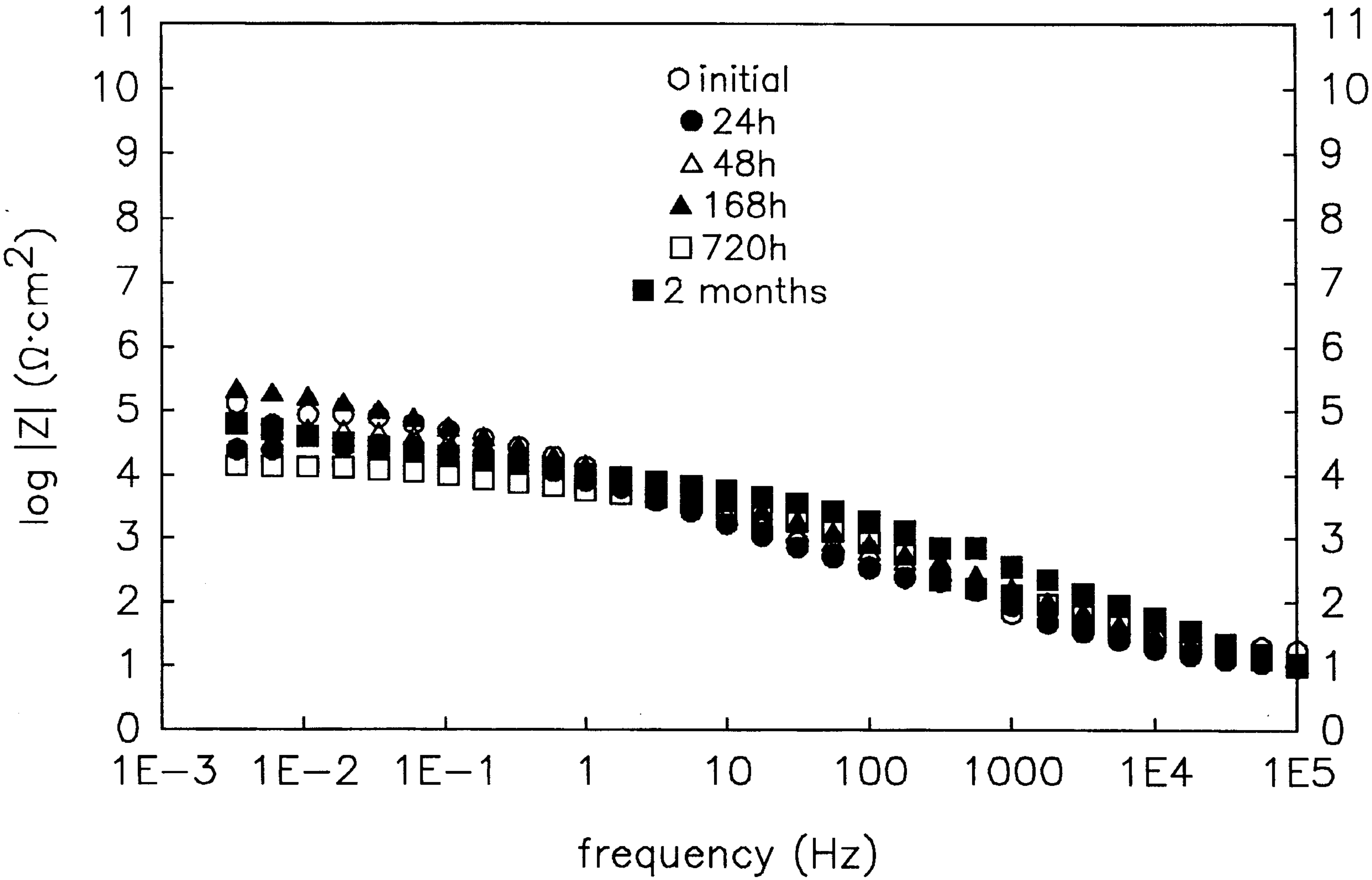

Figure 132. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in MoZnP saturated 0.01 M K_2SO_4.

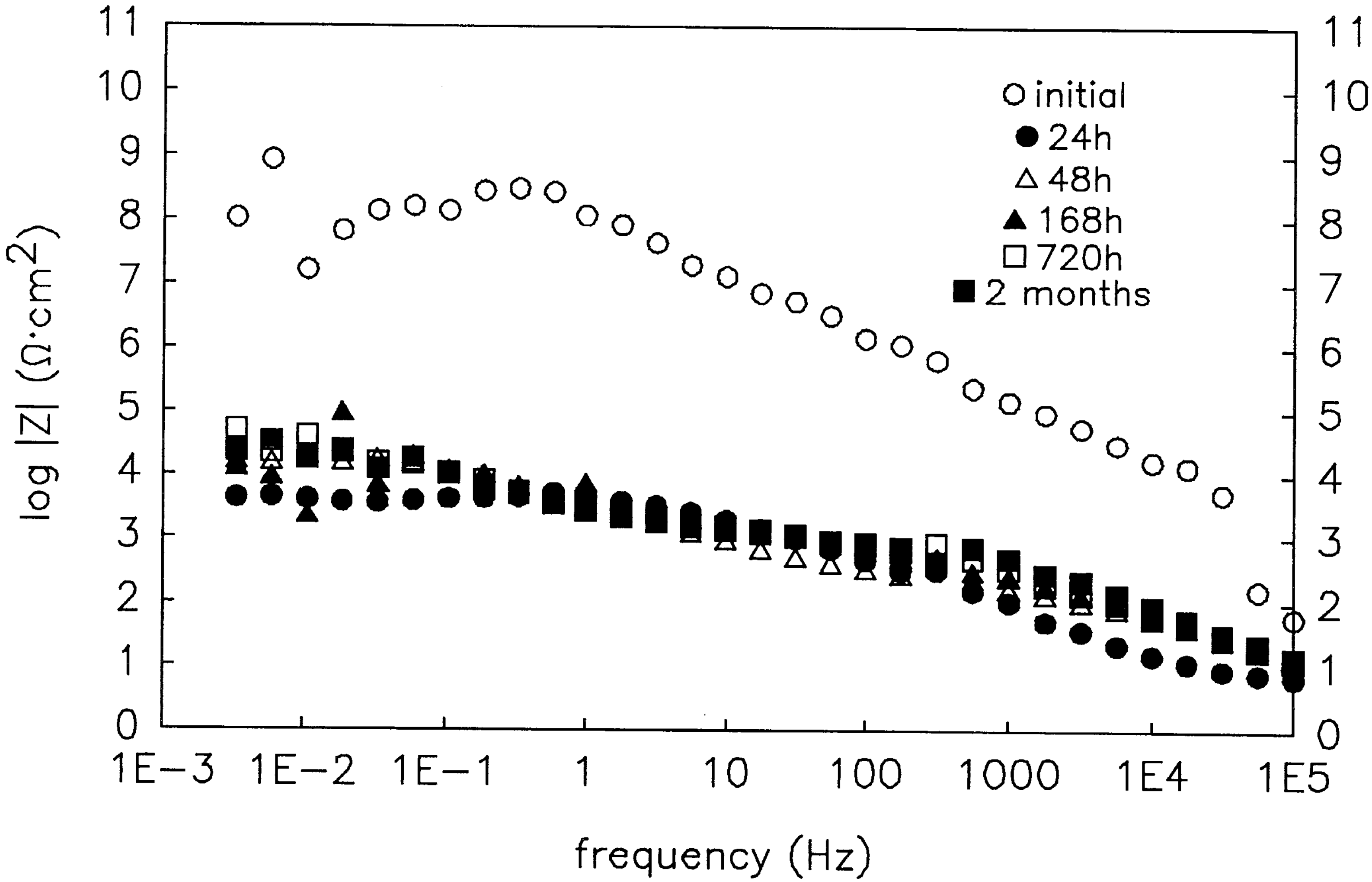

Figure 133. Impedance spectra of Epoxy 1 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in ZnCin saturated 0.01 M K_2SO_4.

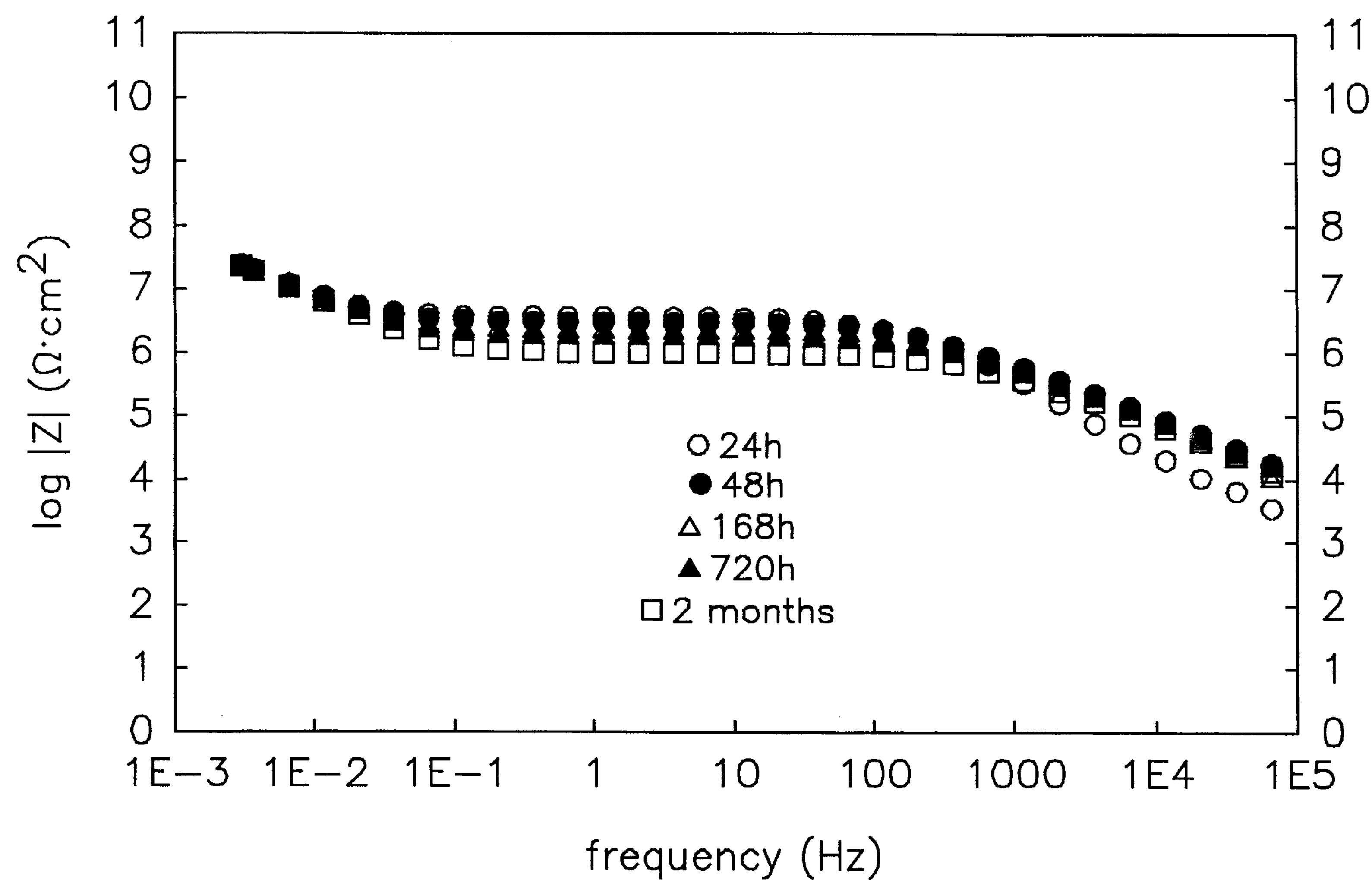

Figure 136. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al in 0.01 M K_2SO_4 (trial 1).

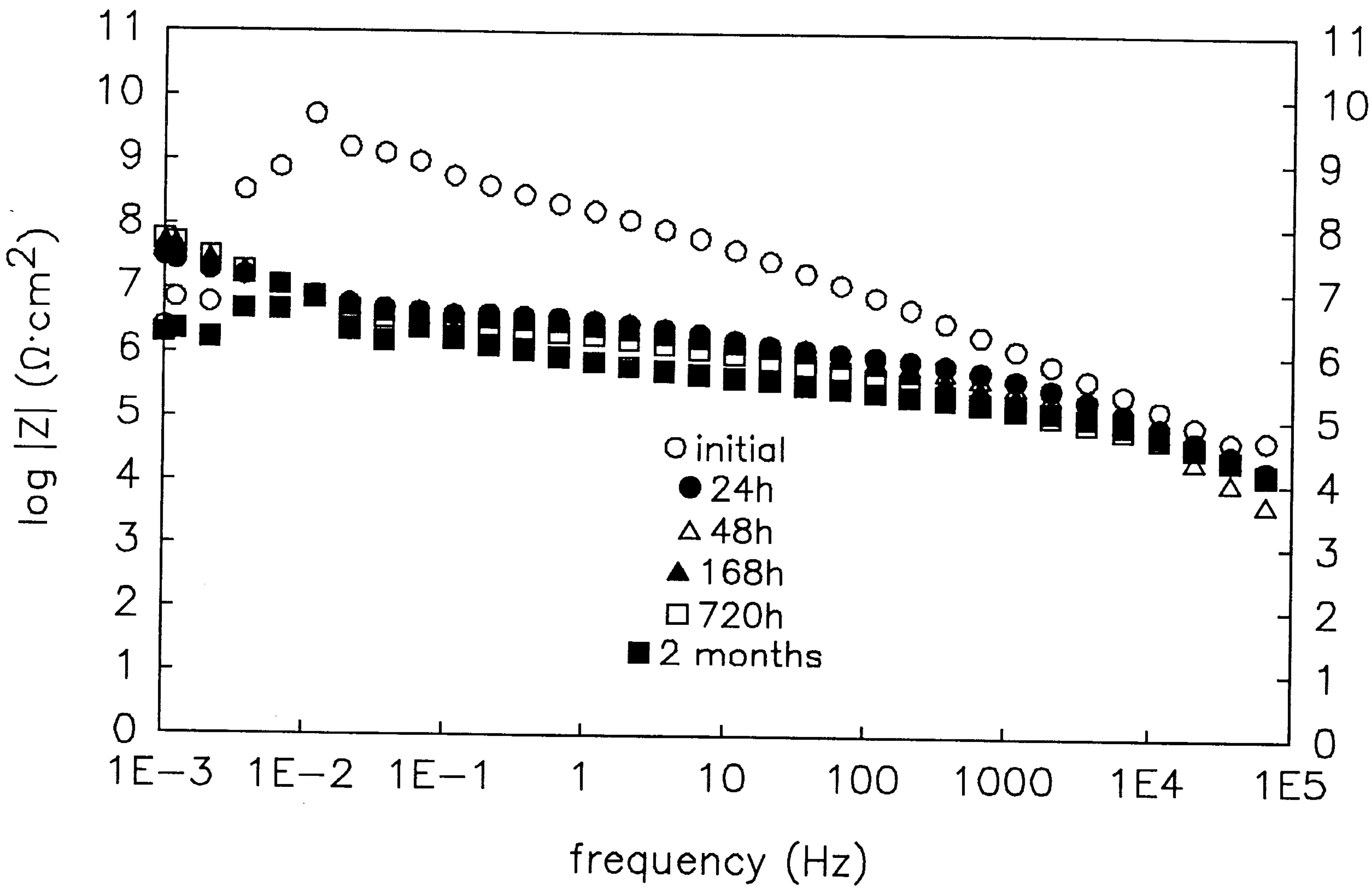

Figure 137. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al in 0.01 M K_2SO_4 (trial 2).

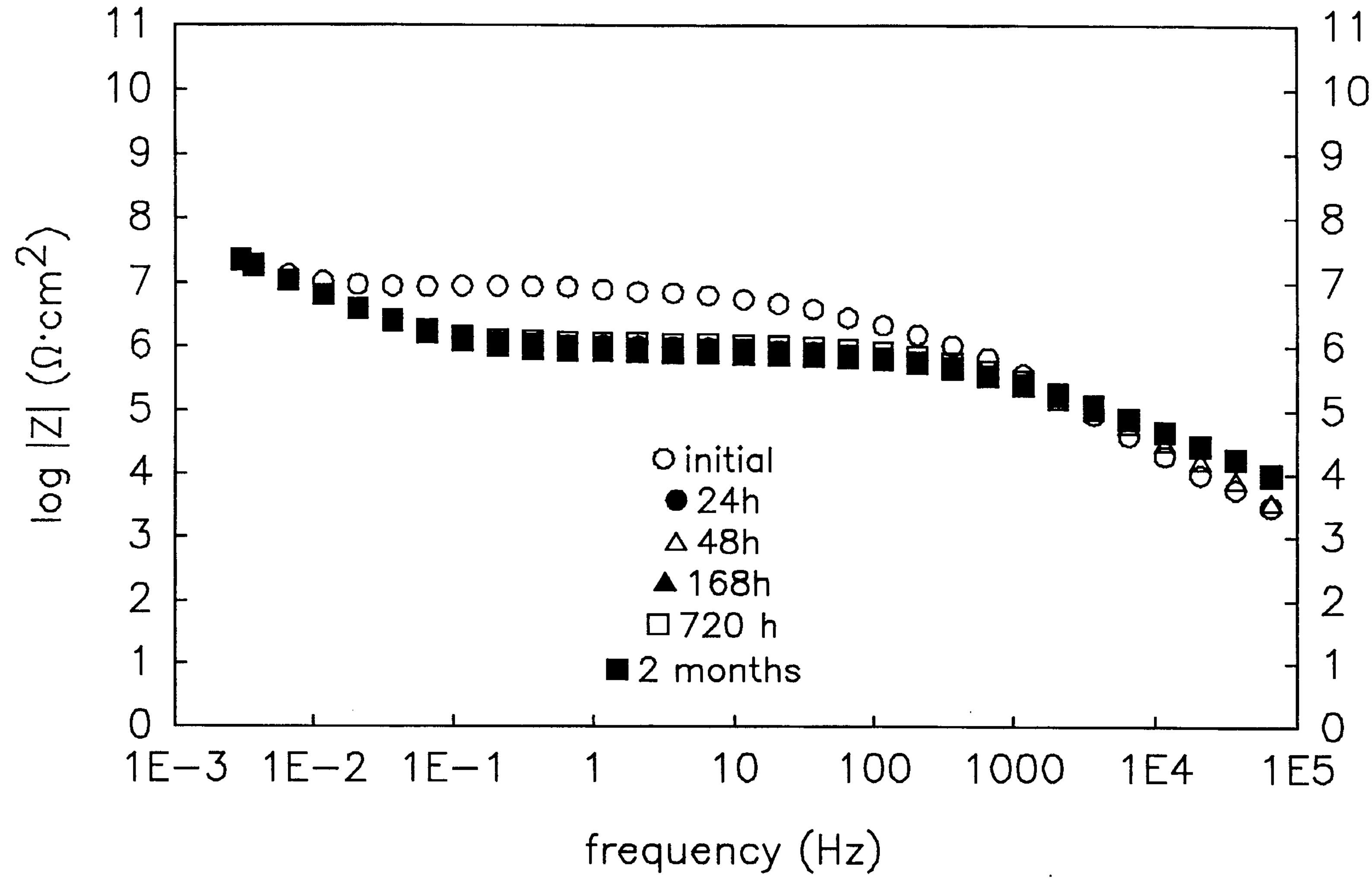

Figure 138. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al in MPSi saturated 0.01 M K_2SO_4 (trial 1).

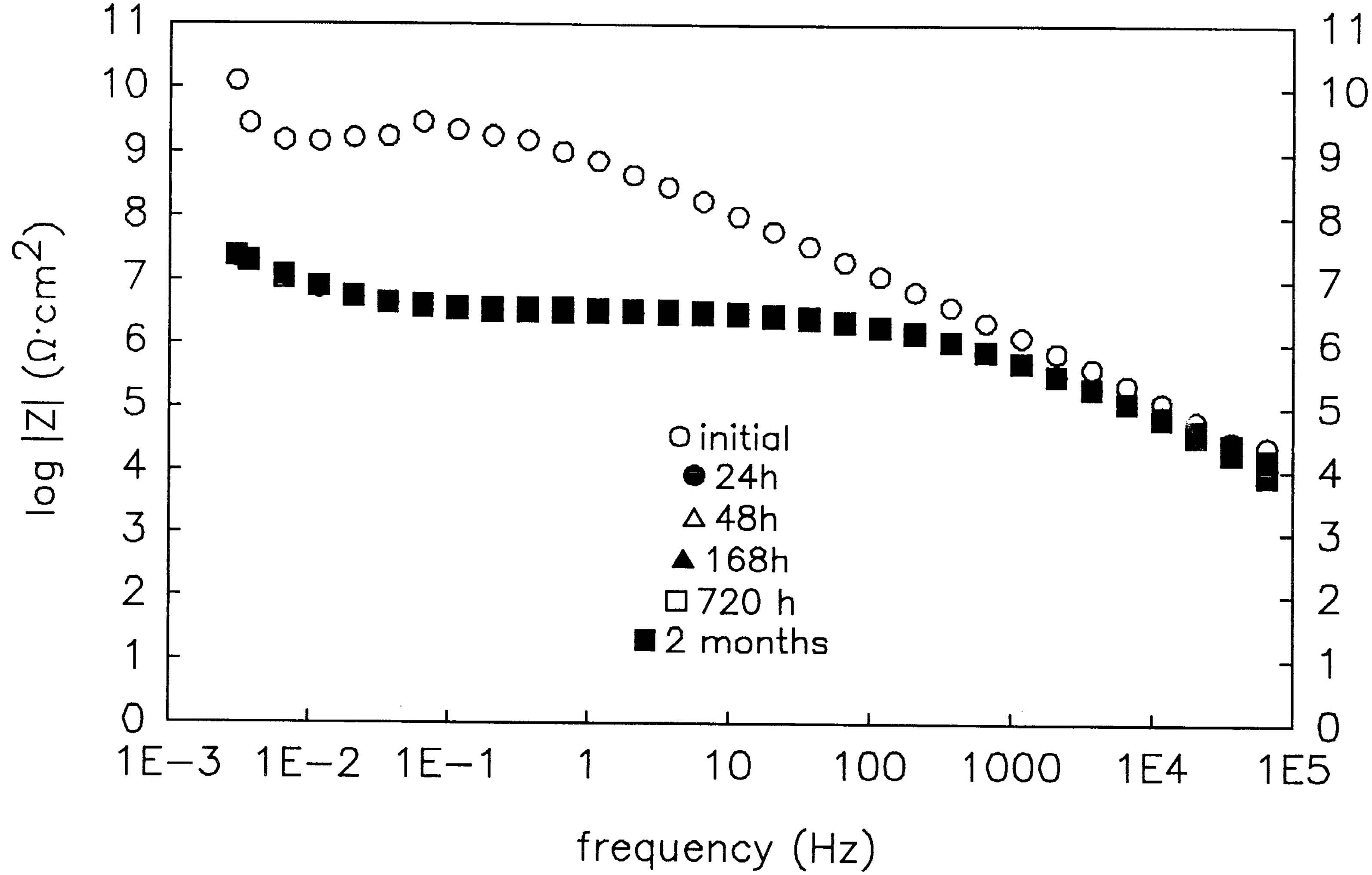

Figure 139. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al in MPSi saturated 0.01 M K_2SO_4 (trial 2).

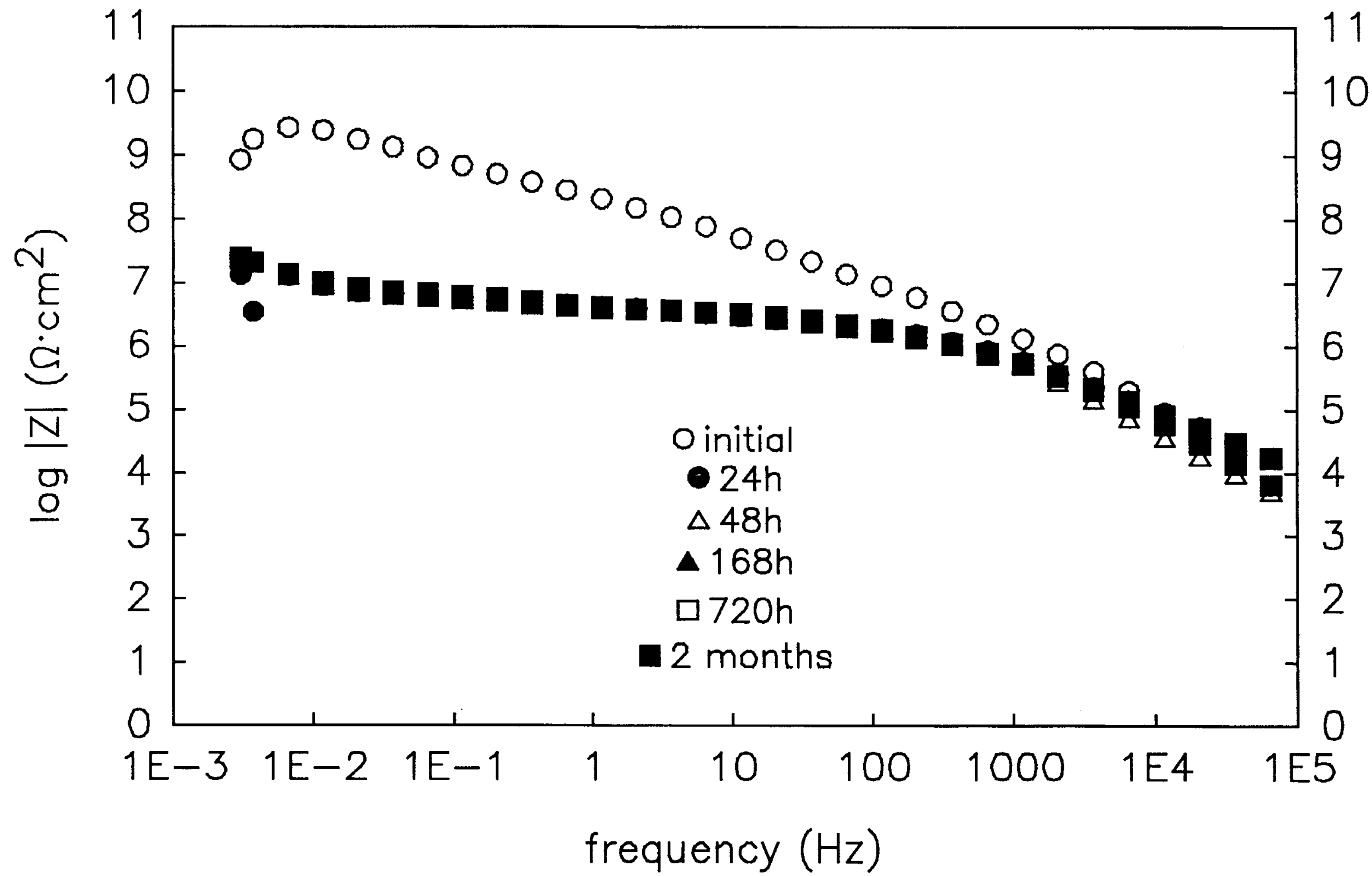

Figure 140. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al in ZnoN saturated 0.01 M K_2SO_4.

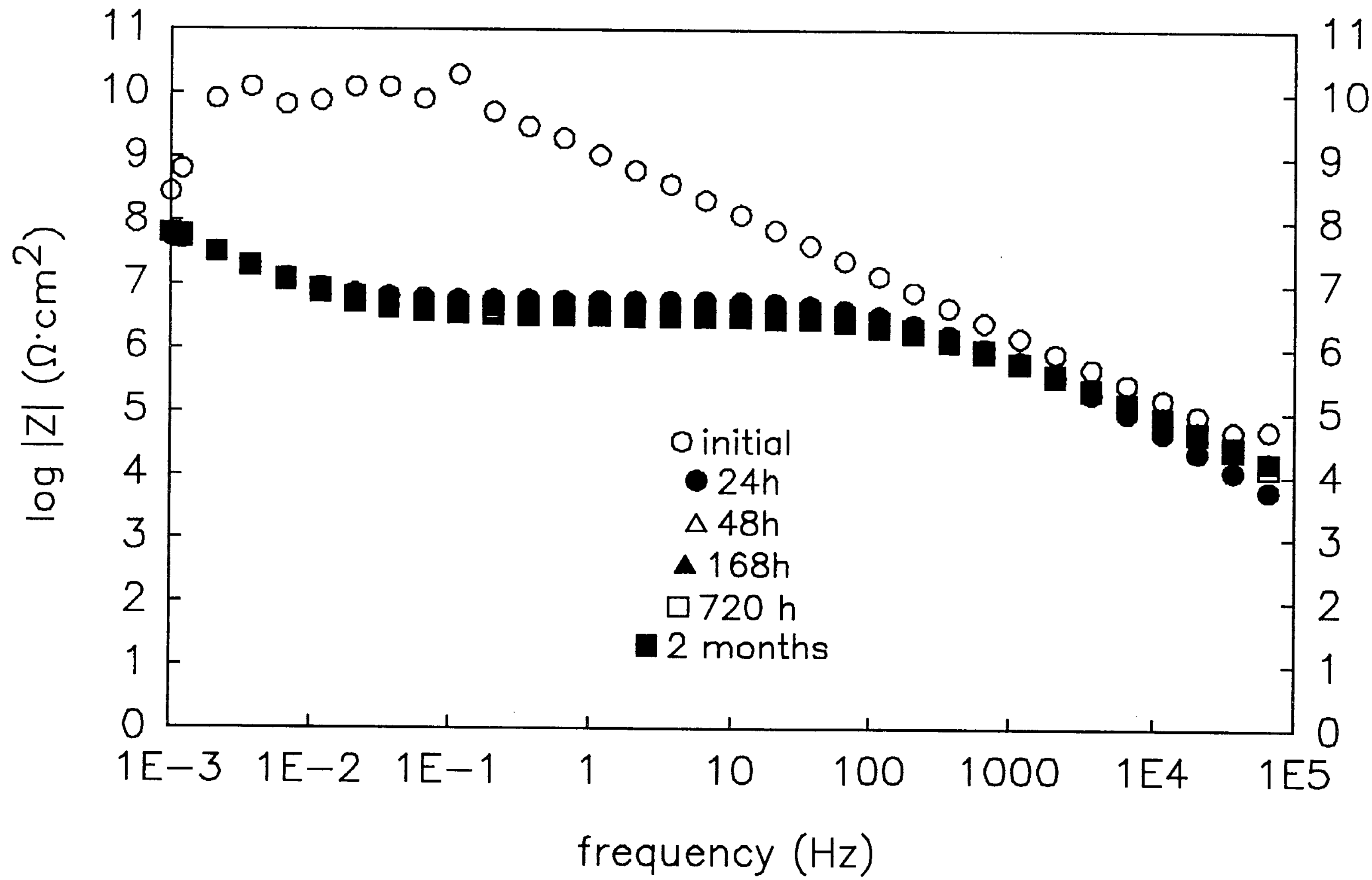

Figure 141. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al with 0.3% MPSi in the coating in 0.01 M K_2SO_4.

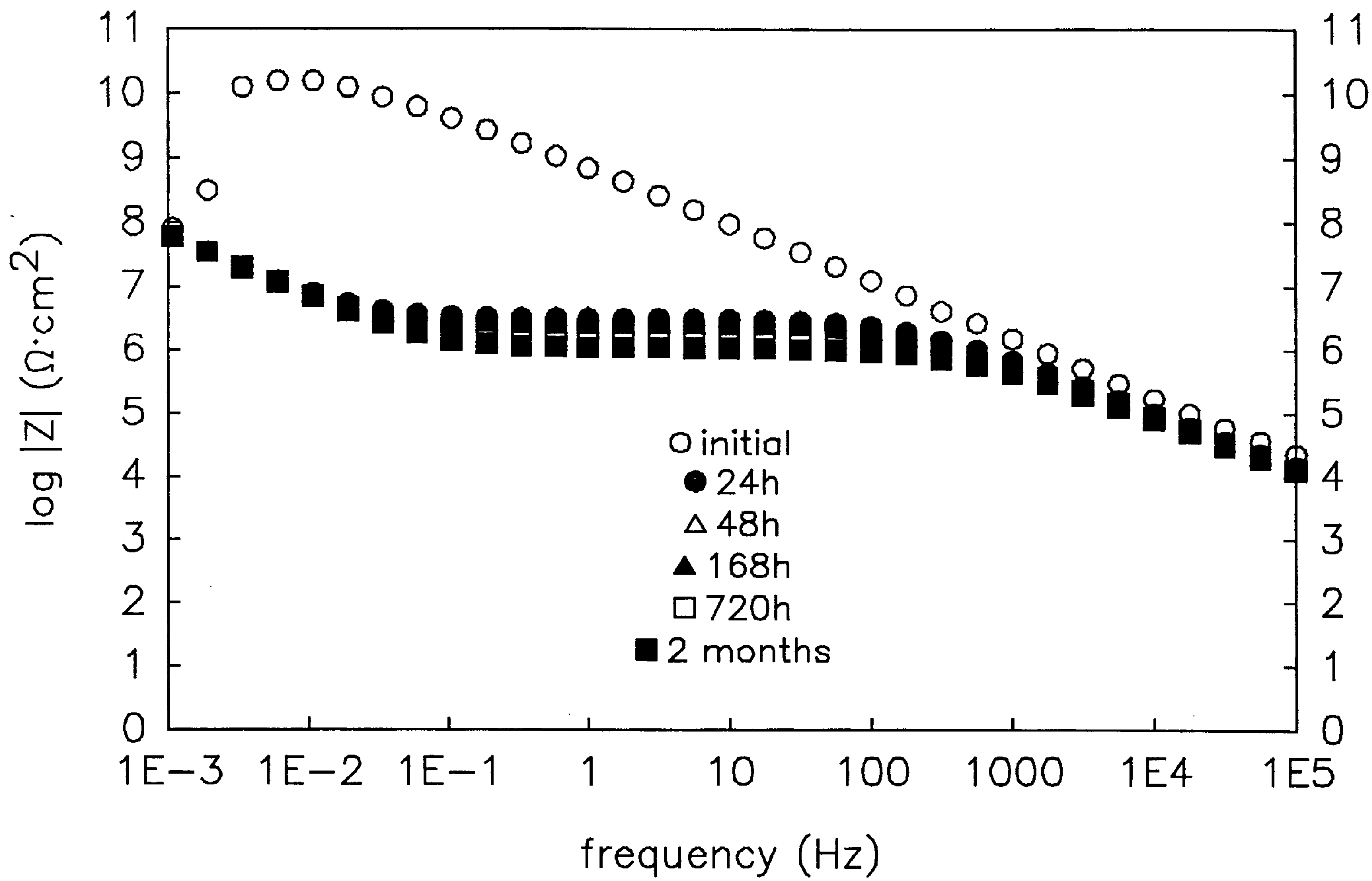

Figure 142. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al with 0.03% ZnoN in the coating in 0.01 M K_2SO_4.

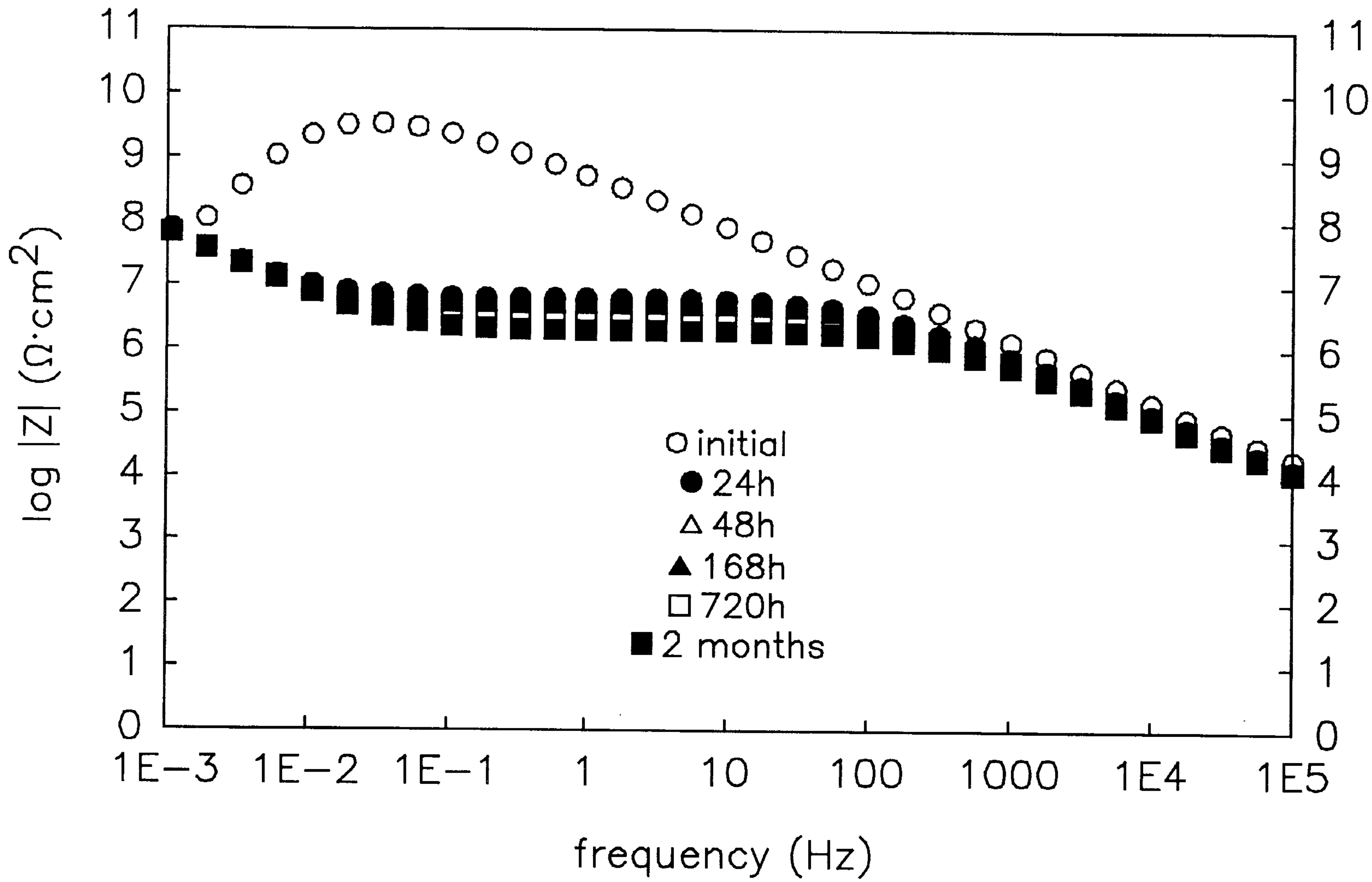

Figure 143. Impedance spectra of epoxy 332/736/3140 cured 2 h at 100°C on CCC Al with 0.3% BaBor in the coating in 0.01 M K_2SO_4.

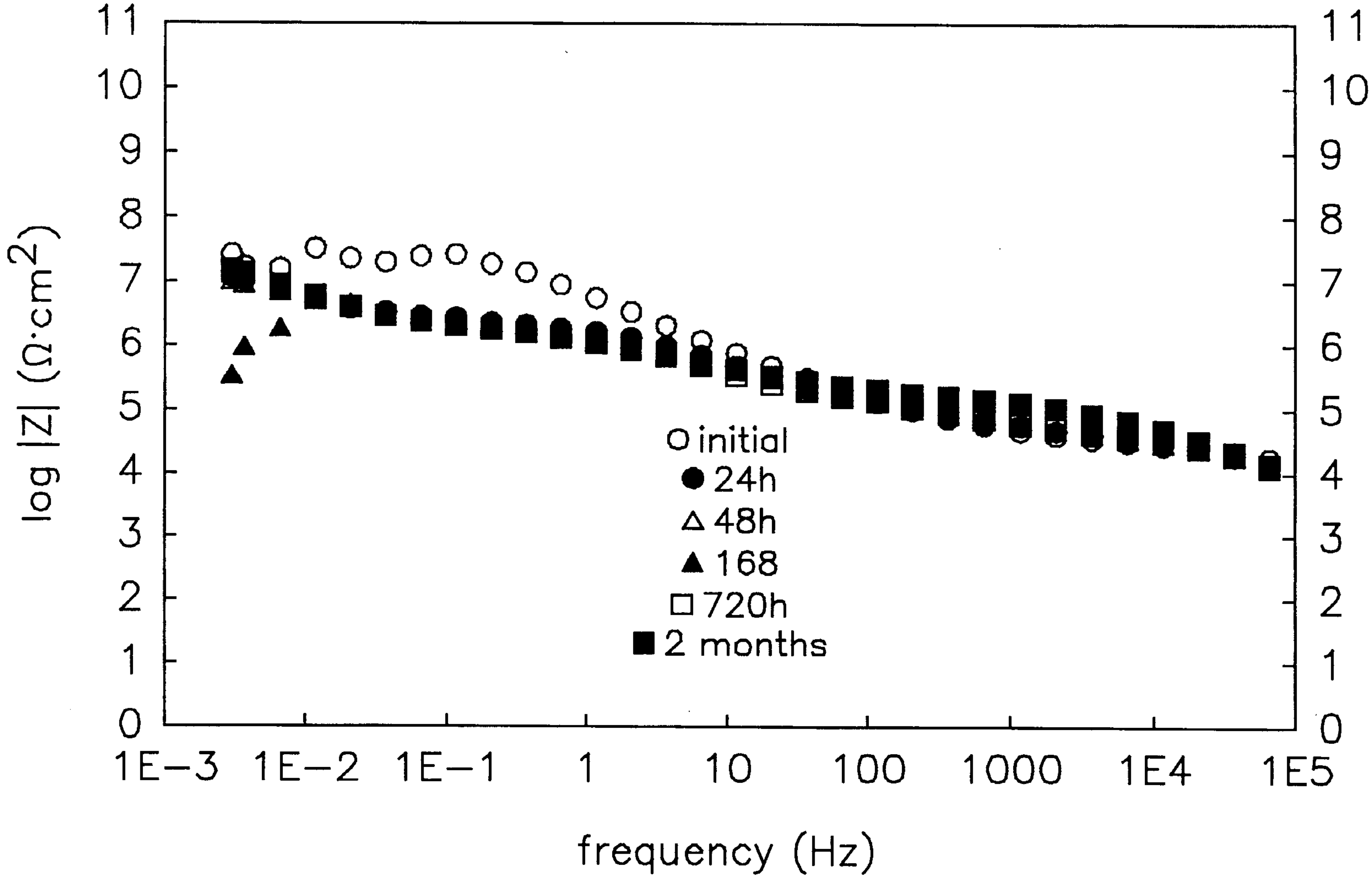

Figure 144. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in 0.01 M K_2SO_4.

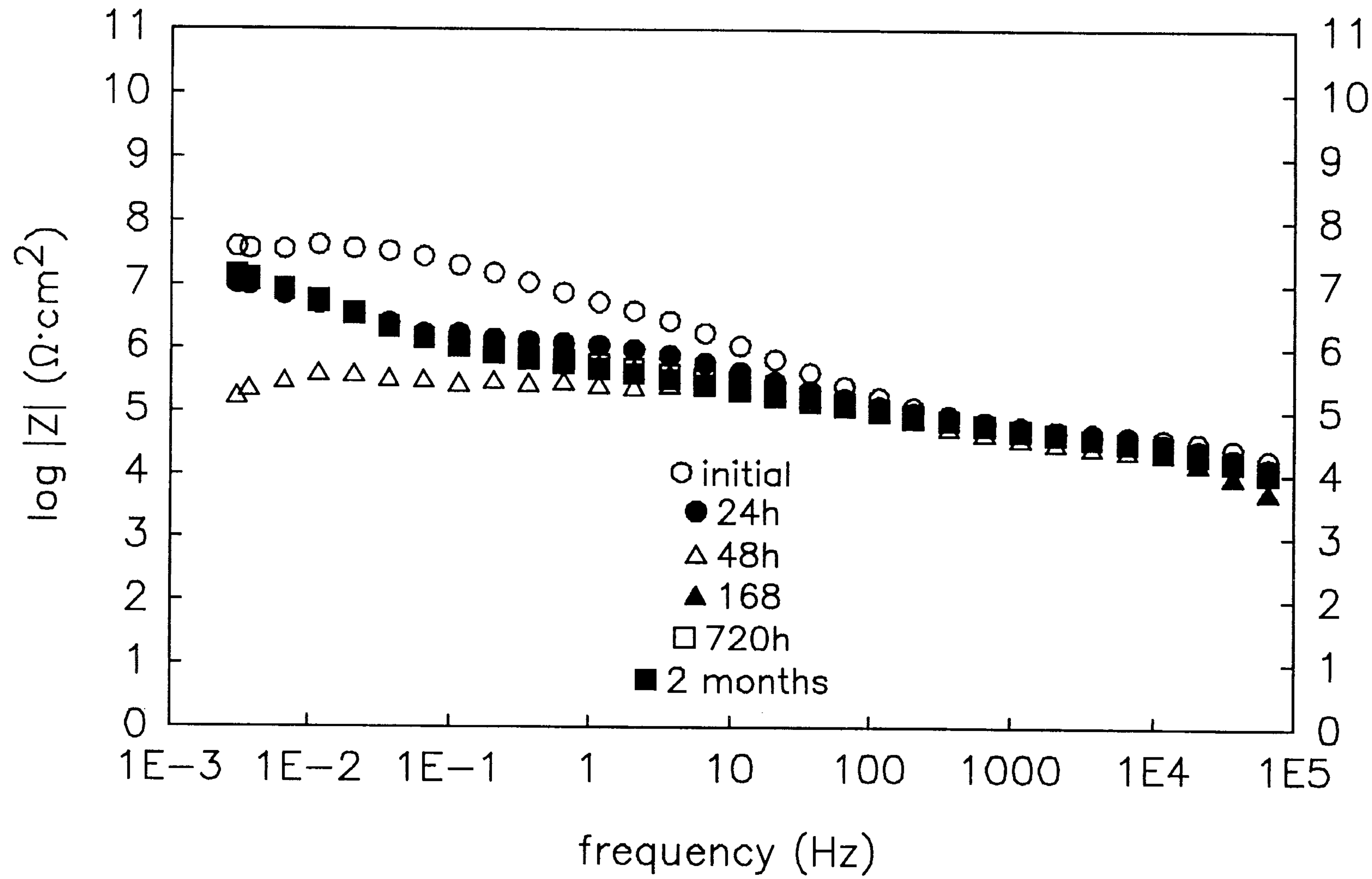

Figure 145. Impedance spectra of Epoxy 2 cured 2 h at 100°C with 0.3% MPSi in the coating on CCC Al with an 800 μm diameter defect in 0.01 M K_2SO_4.

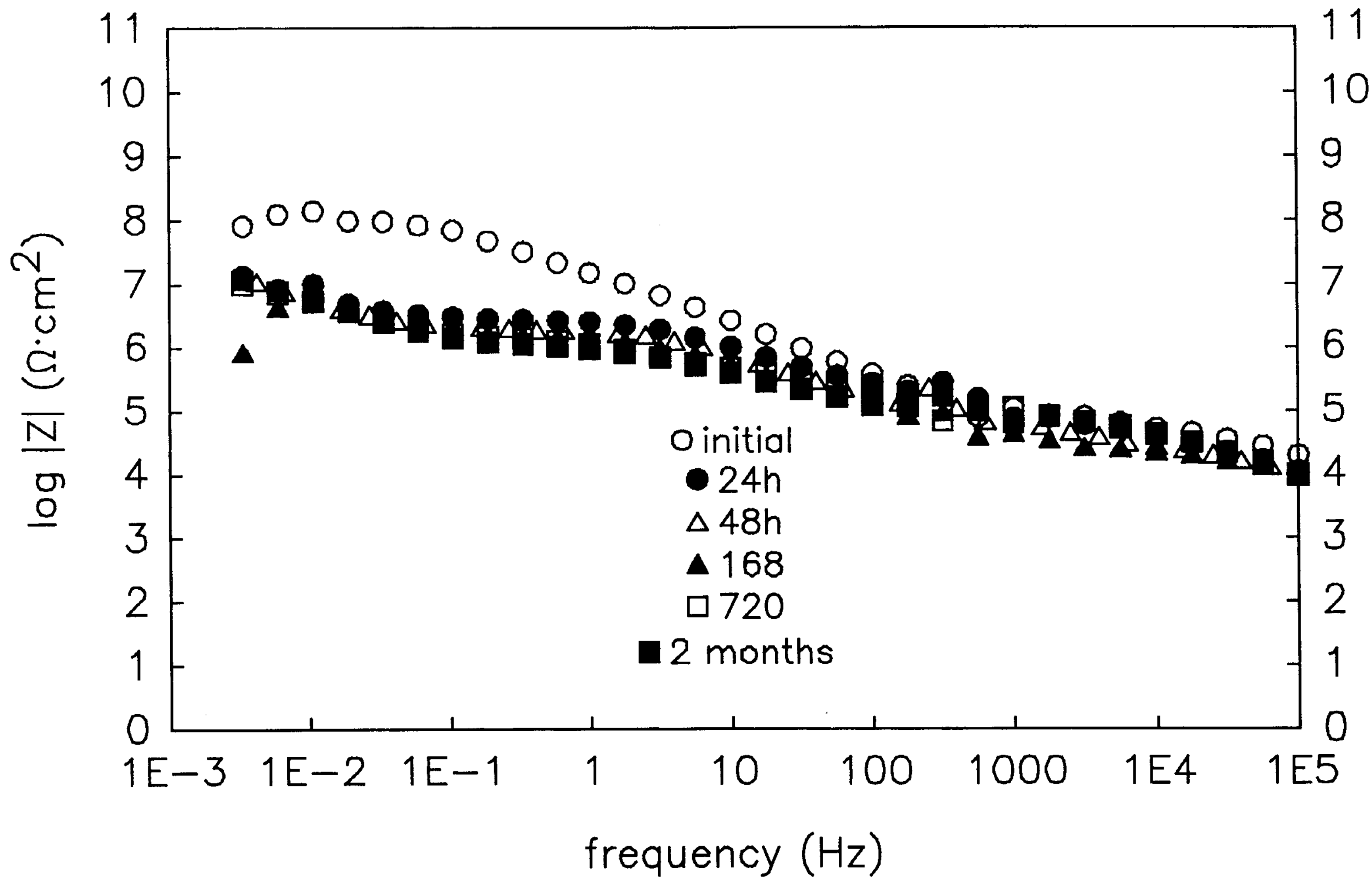

Figure 146. Impedance spectra of Epoxy 2 cured 2 h at 100°C with 0.3% ZnoN in the coating on CCC Al with an 800 μm defect in 0.01 M K_2SO_4.

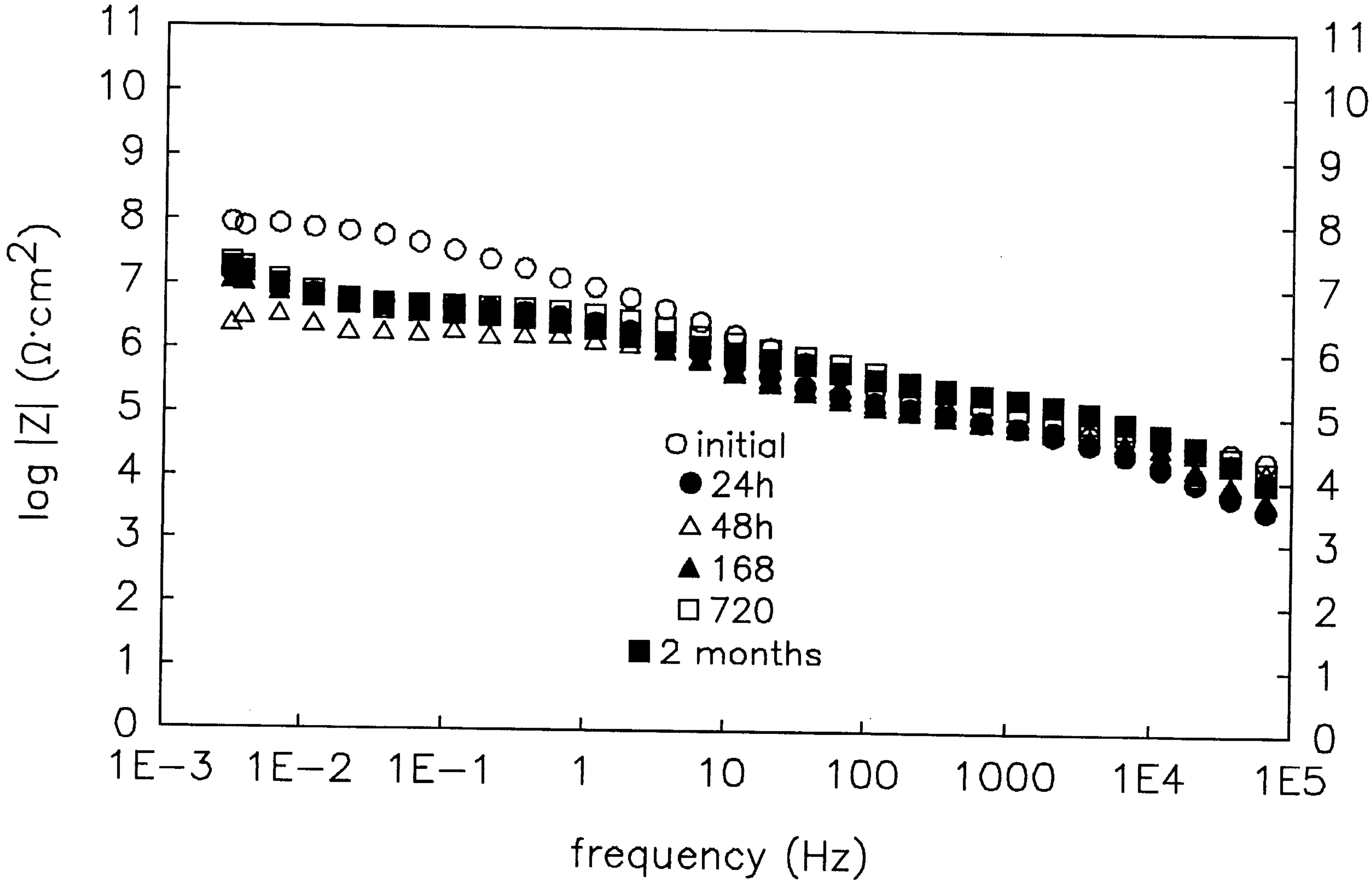

Figure 147. Impedance spectra of Epoxy 2 cured 2 h at 100°C with 0.3% BaBor in the coating on CCC Al with an 800 µm diameter defect in 0.01 M K_2SO_4.

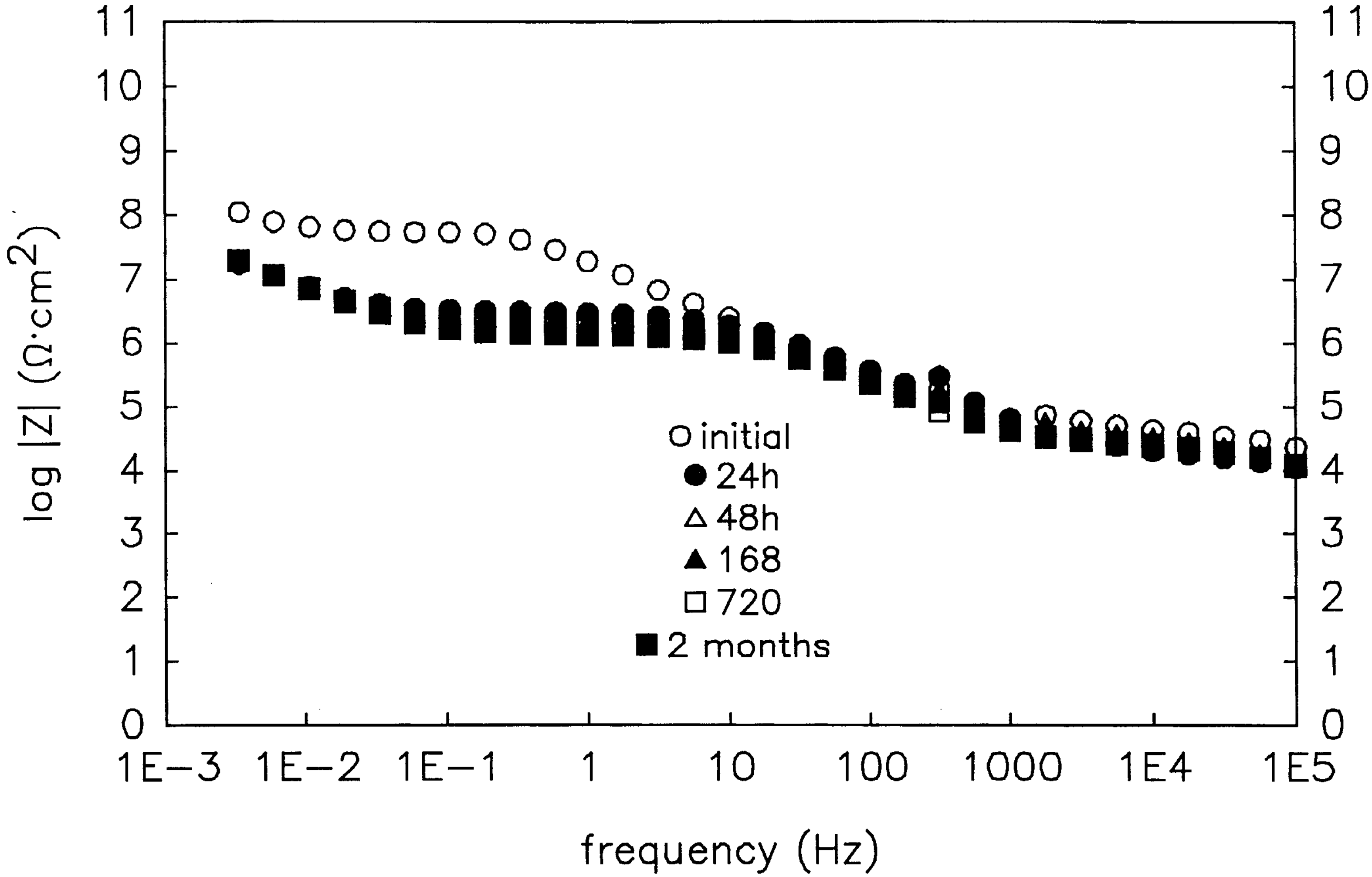

Figure 148. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in MPSi saturated 0.01 M K_2SO_4.

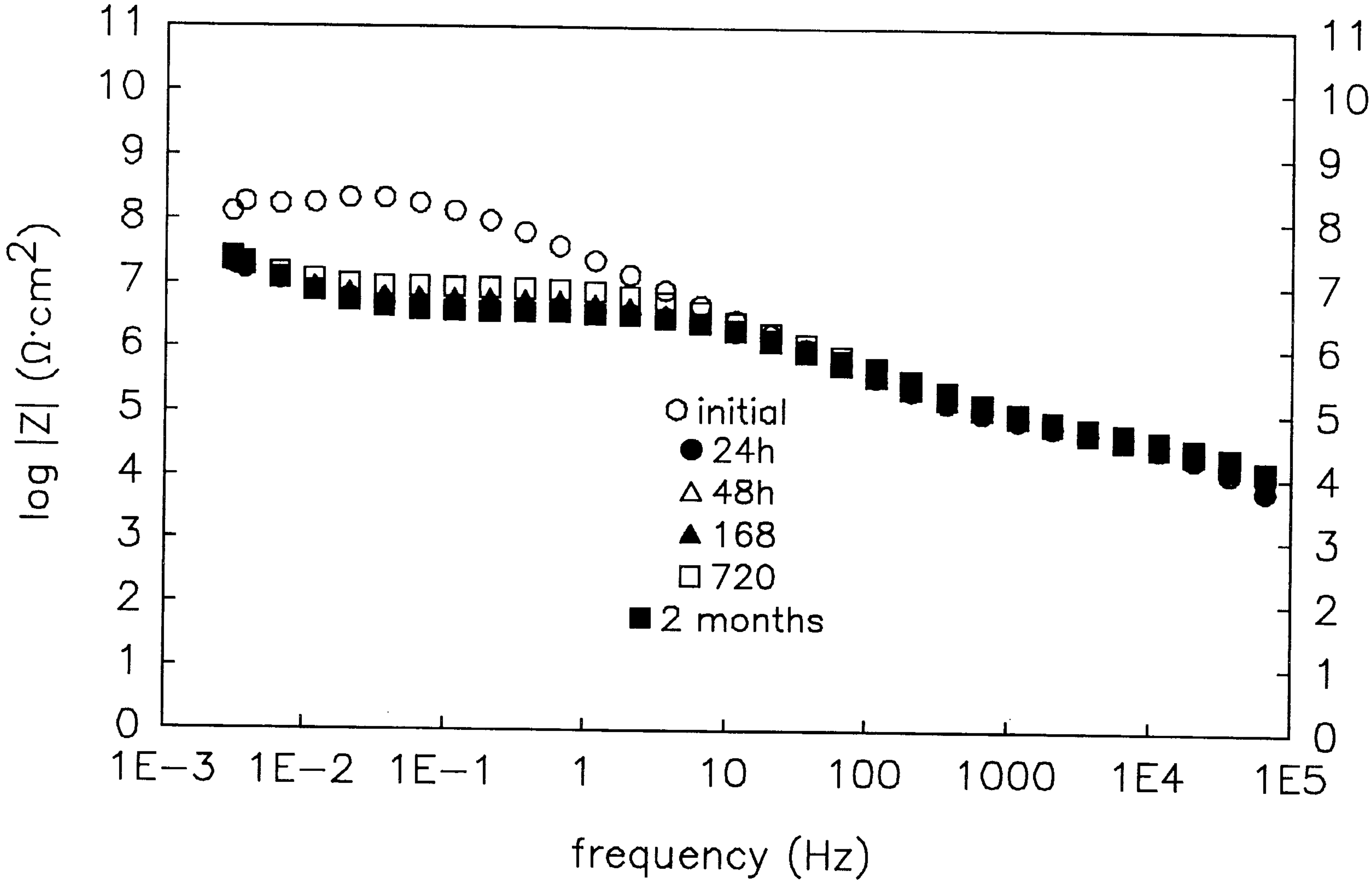

Figure 149. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in the coating in ZnoN saturated 0.01 M K_2SO_4.

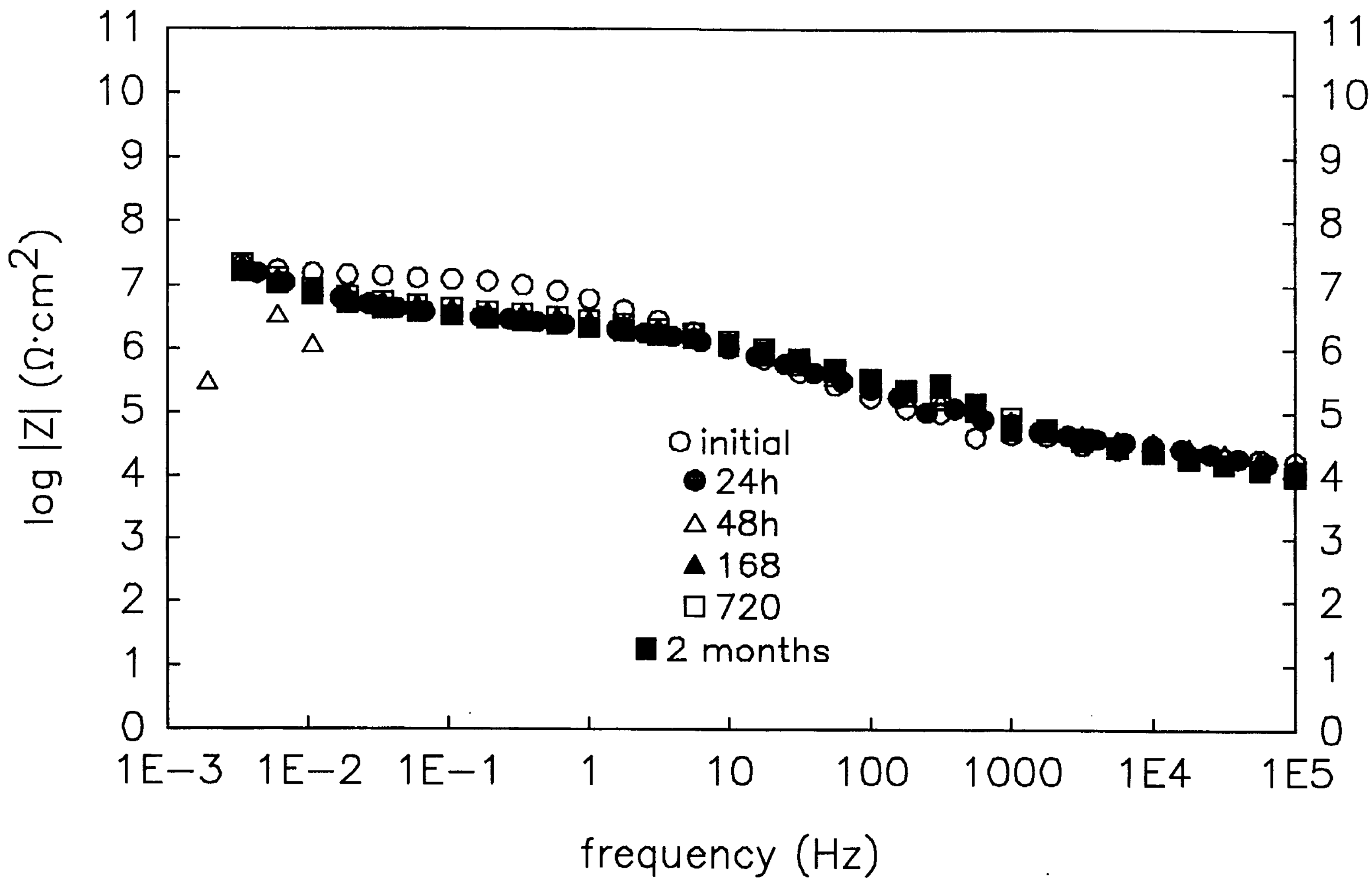

Figure 150. Impedance spectra of Epoxy 2 cured 2 h at 100°C on CCC Al with an 800 μm diameter defect in BaBor saturated 0.01 M K_2SO_4.

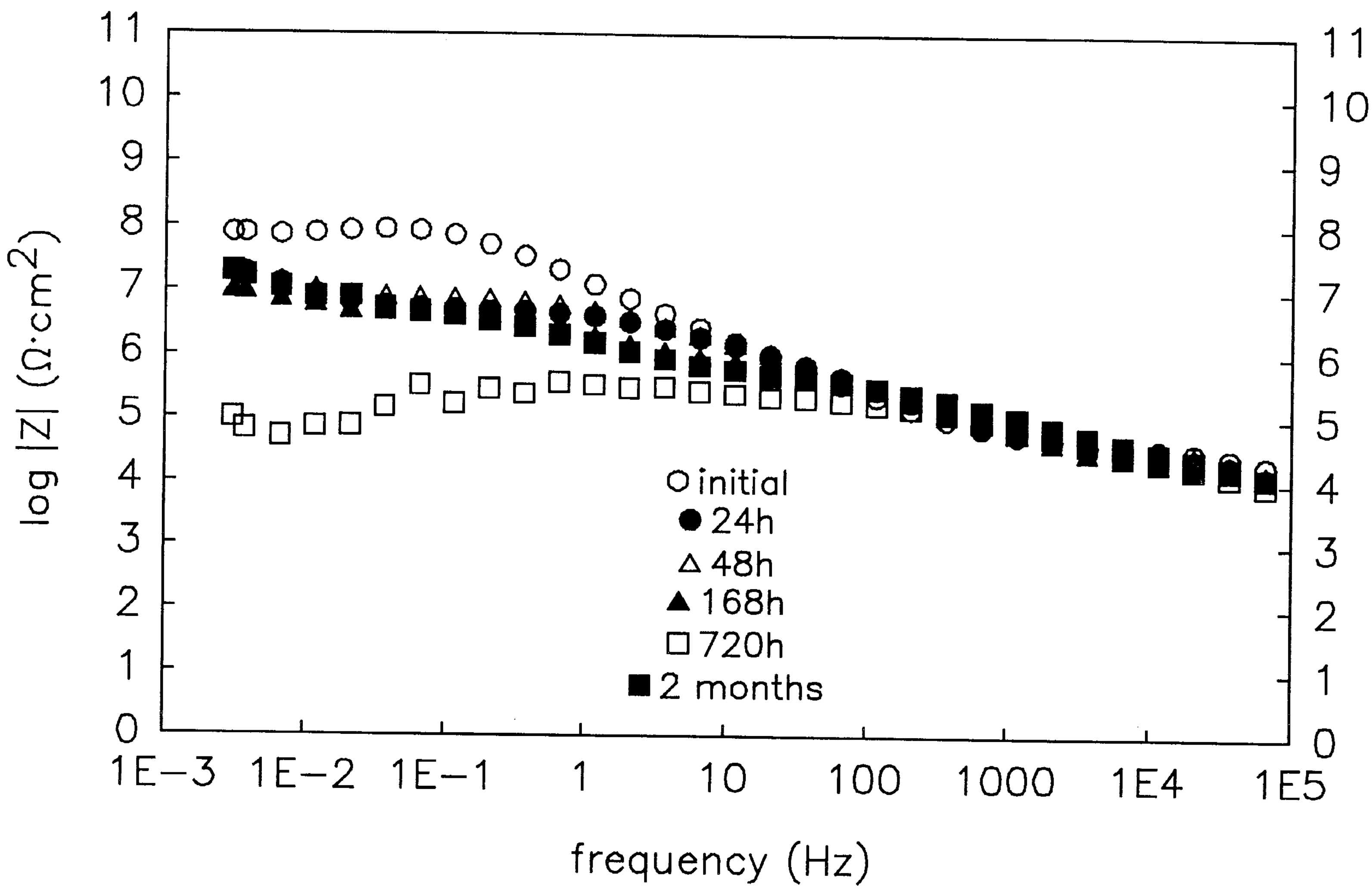

Figure 151. Impedance spectra of epoxy 332/736/3140 cured 2 h at 100°C with 0.3% MPSi in the coating on CCC Al with an 800 μm diameter defect in MPSi saturated 0.01 M K_2SO_4.

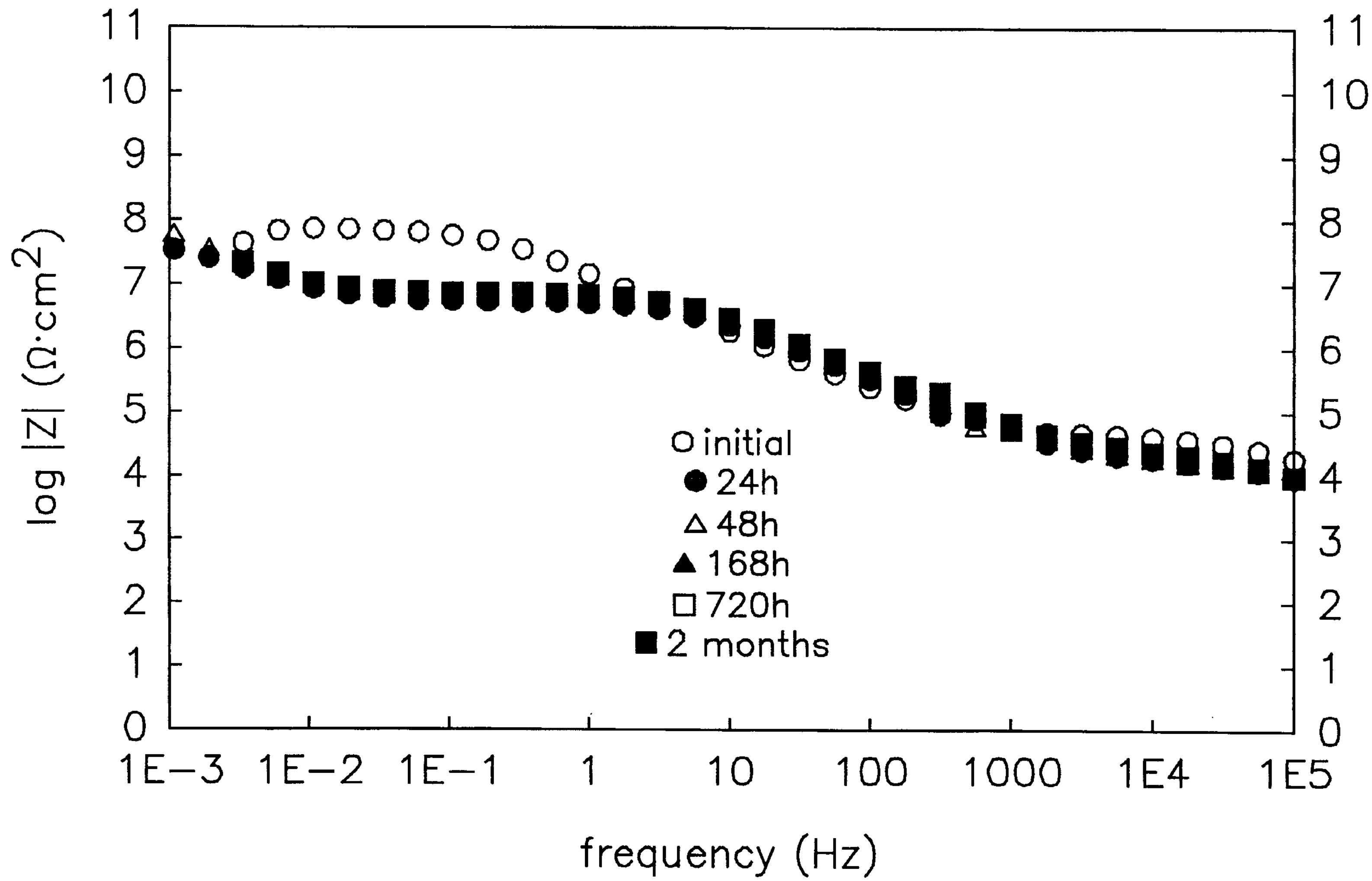

Figure 152. Impedance spectra of epoxy 332/736/3140 cured 2 h at 100°C with 0.3% BaBor in the coating on CCC Al with an 800 μm diameter defect in BaBor saturated 0.01 M K_2SO_4.

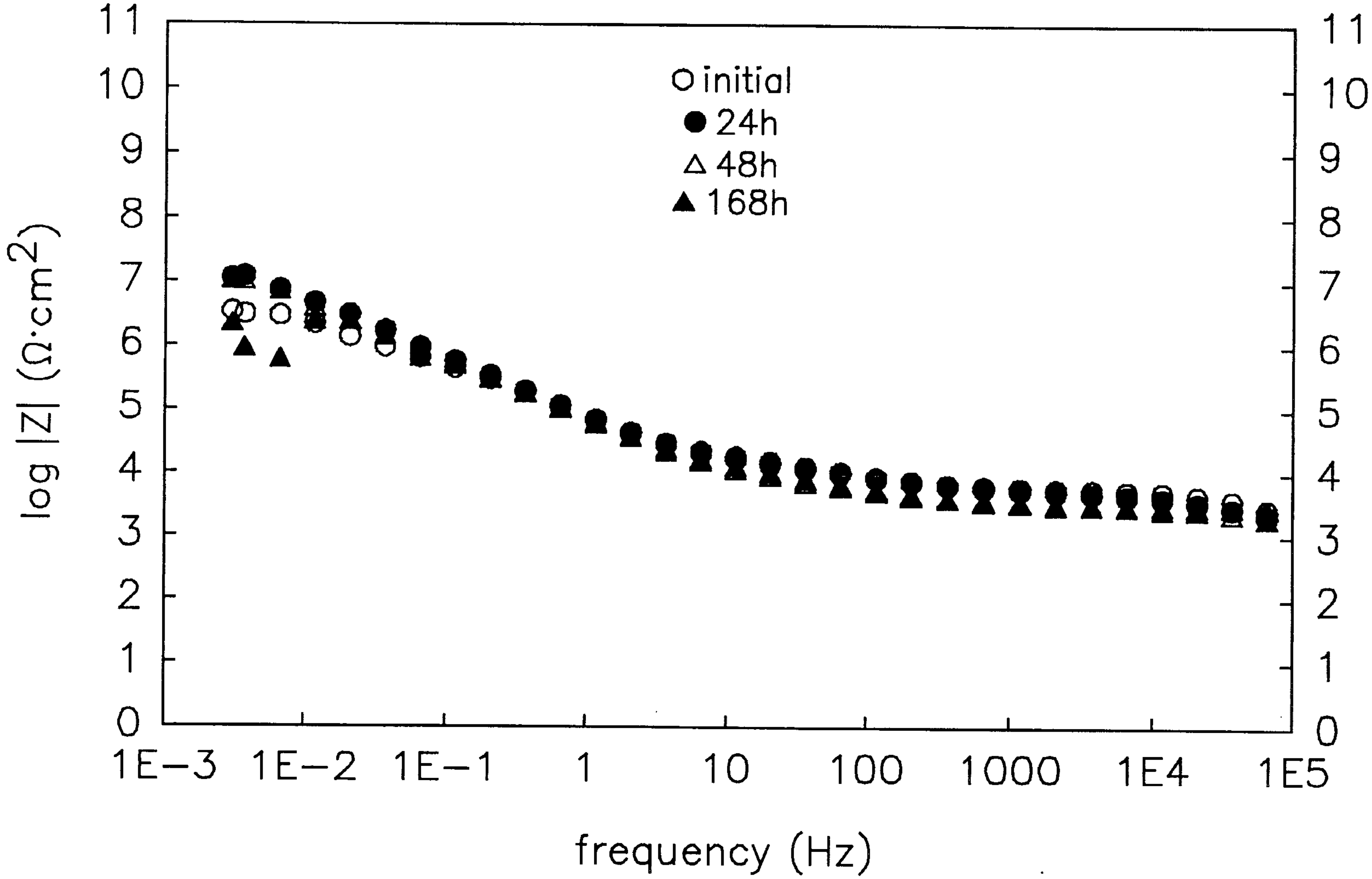

Figure 153. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al in 0.01 M K_2SO_4 (trial 1).

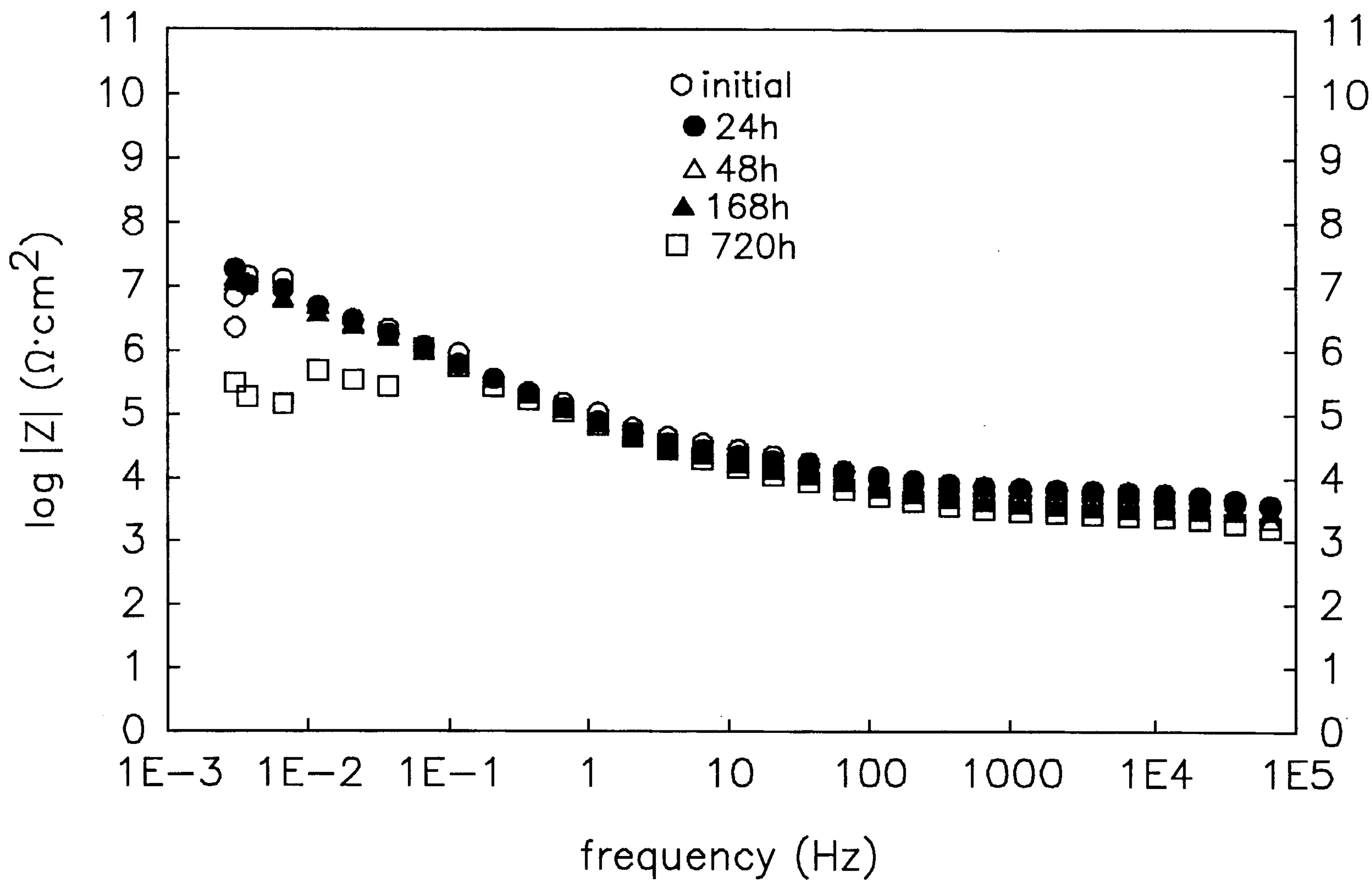

Figure 154. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al in 0.01 M K_2SO_4 (trial 2).

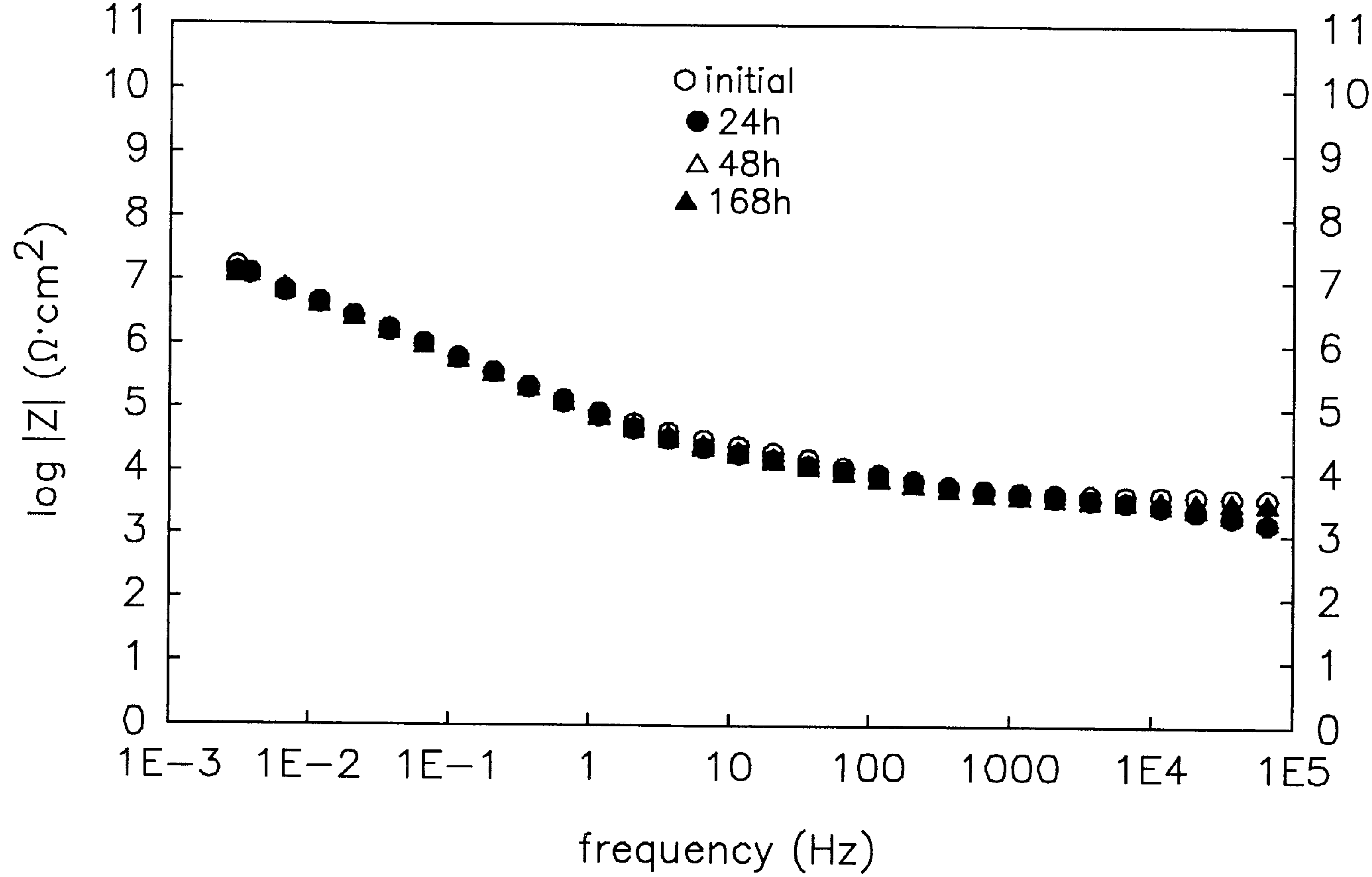

Figure 155. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al with 17% MPSi in the coating in 0.01 M K_2SO_4 (trial 1).

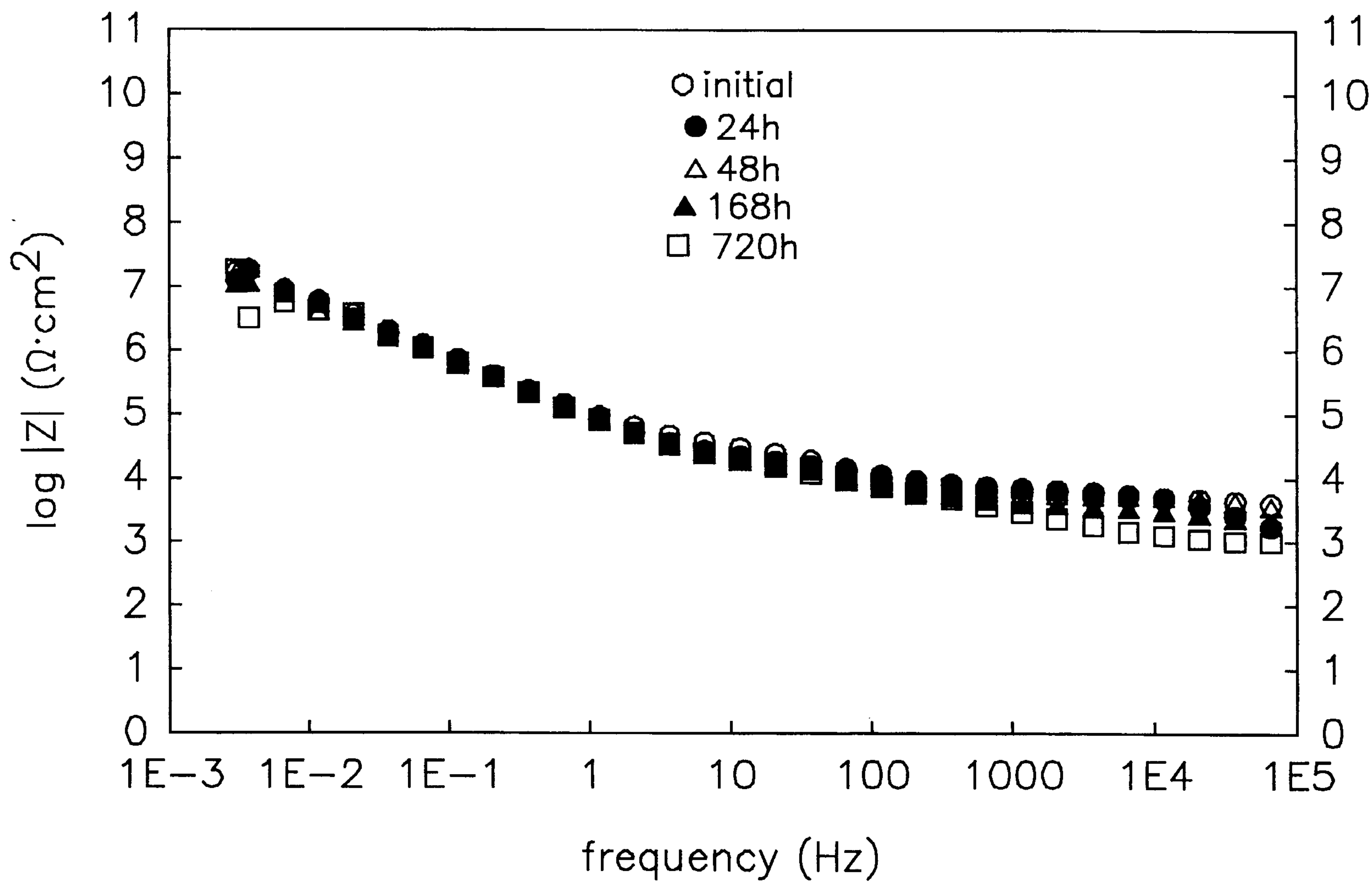

Figure 156. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al with 17% MPSi in the coating in 0.01 M K_2SO_4 (trial 2).

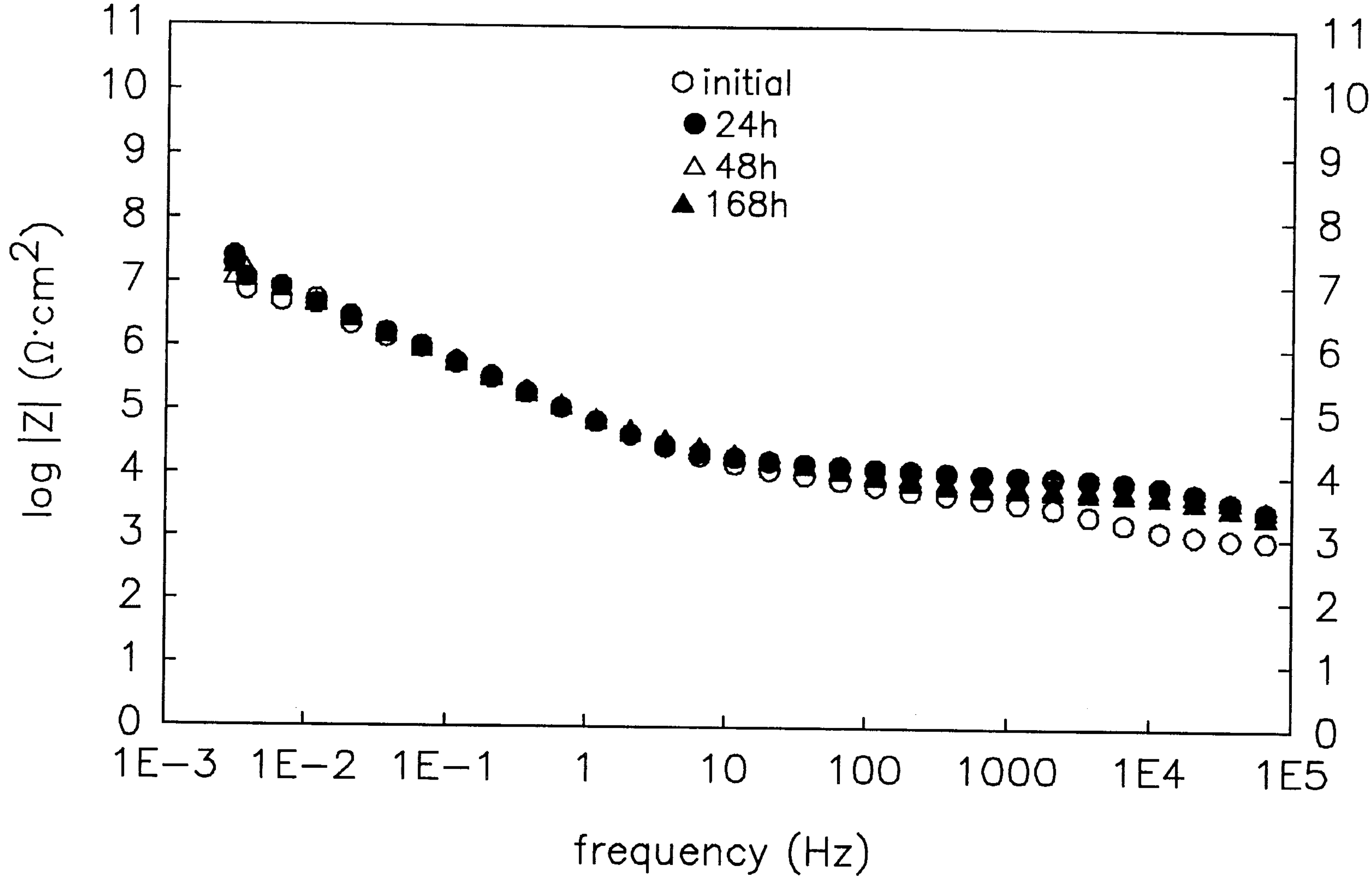

Figure 157. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al with 17% BaBor in the coating in 0.01 M K_2SO_4 (trial 1).

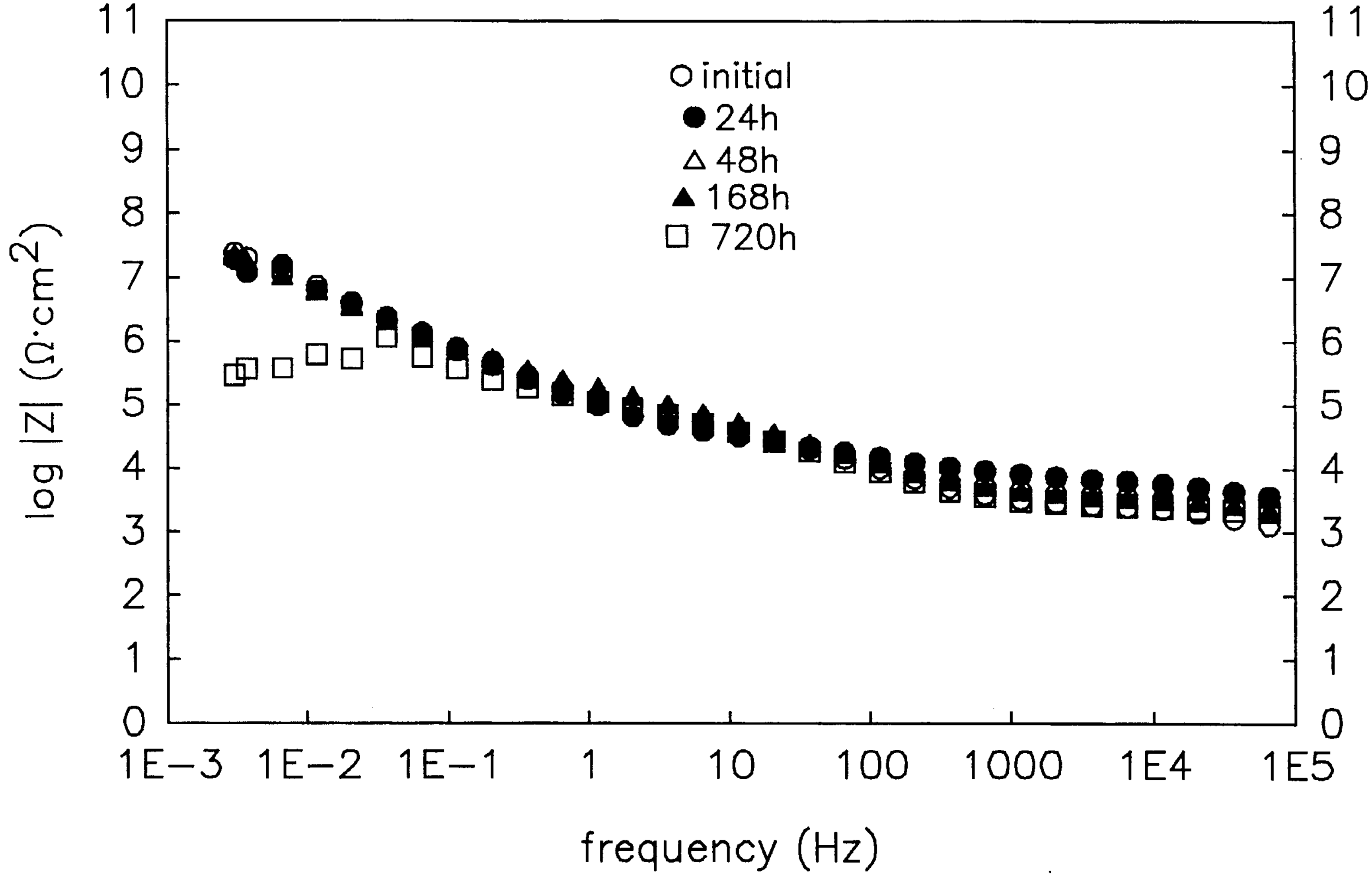

Figure 158. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al with 17% BaBor in the coating in 0.01 M K_2SO_4 (trial 2).

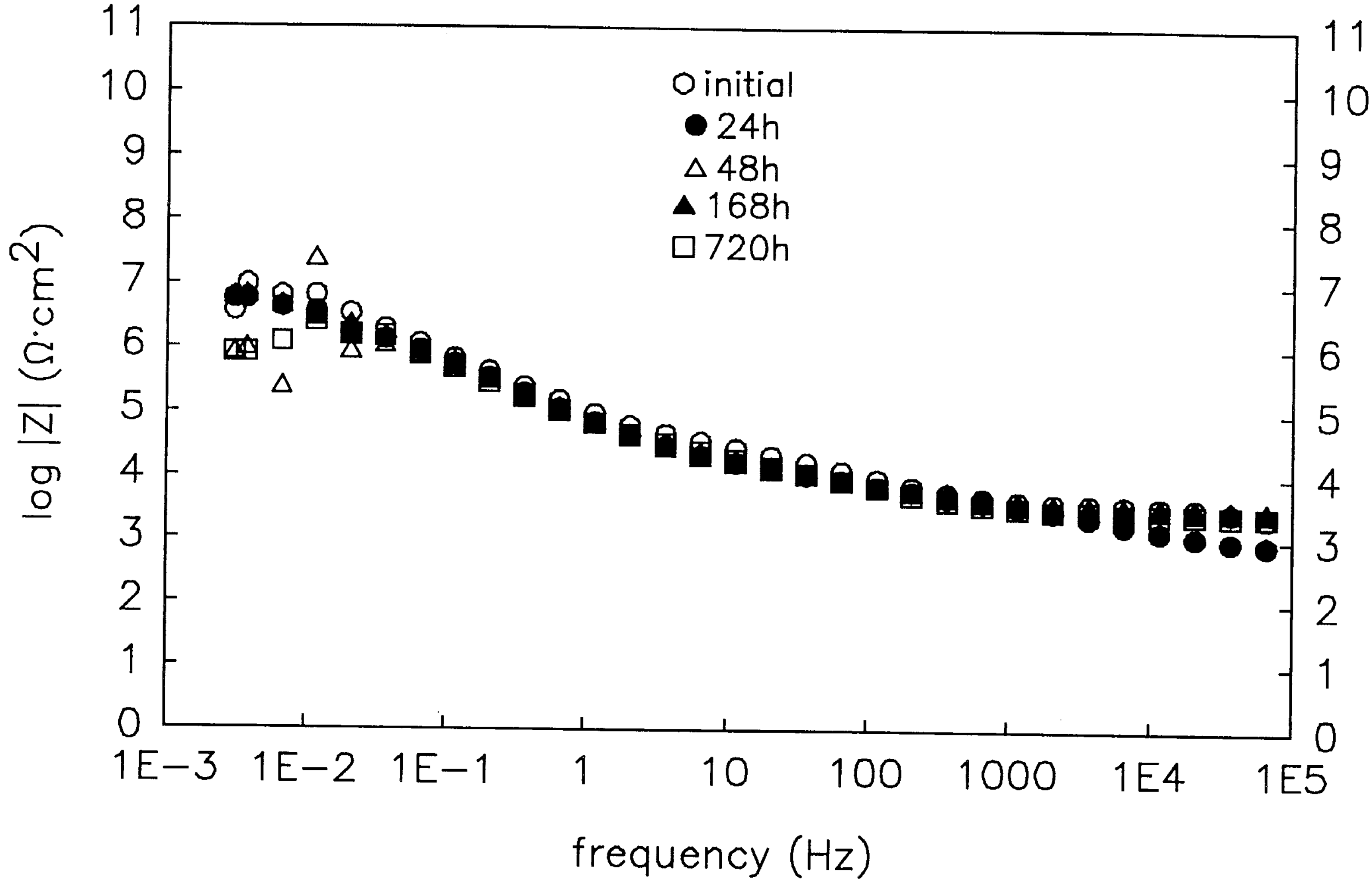

Figure 159. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al in MPSi saturated 0.01 M K_2SO_4.

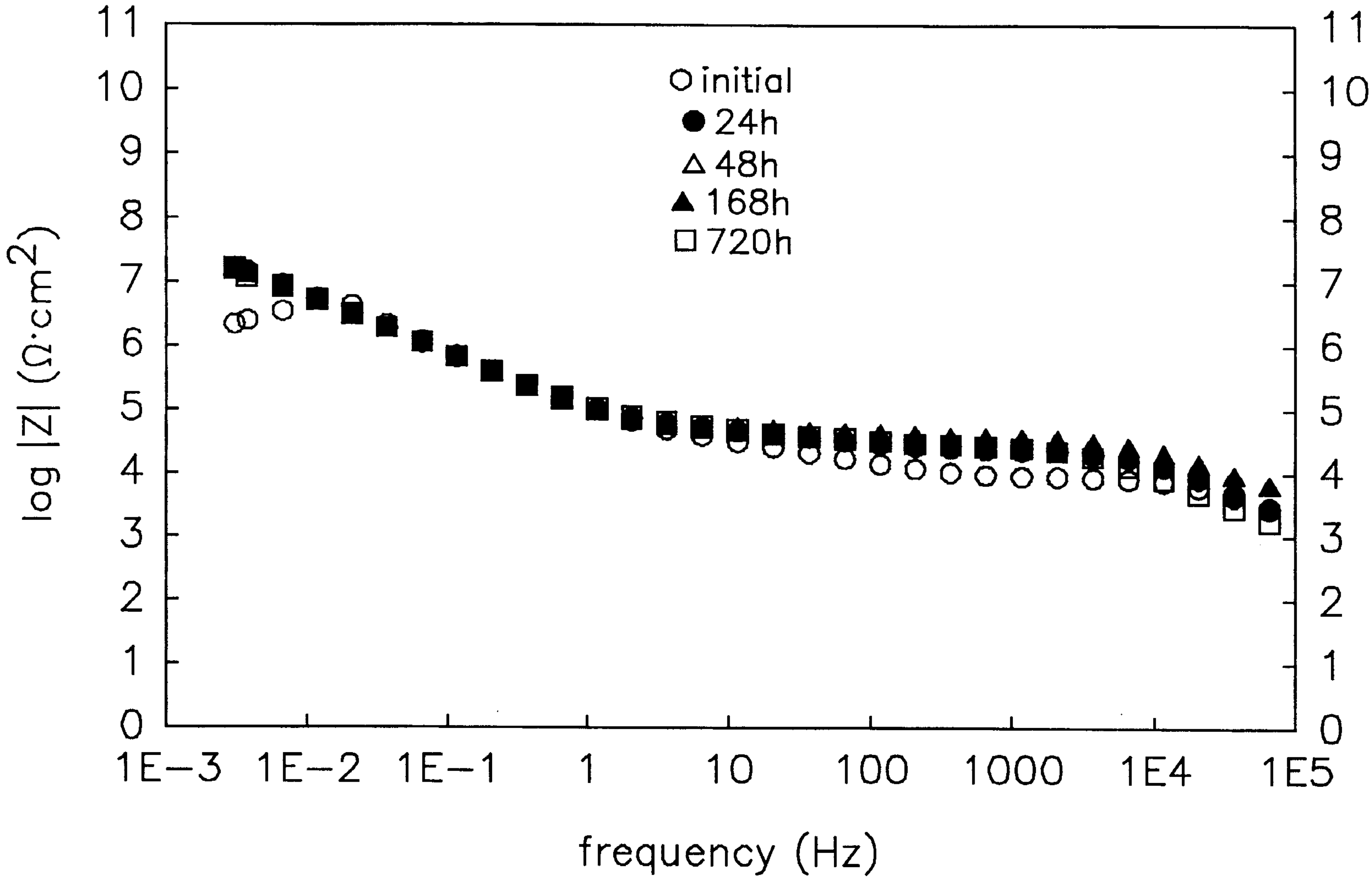

Figure 160. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al in BaBor saturated 0.01 M K_2SO_4.

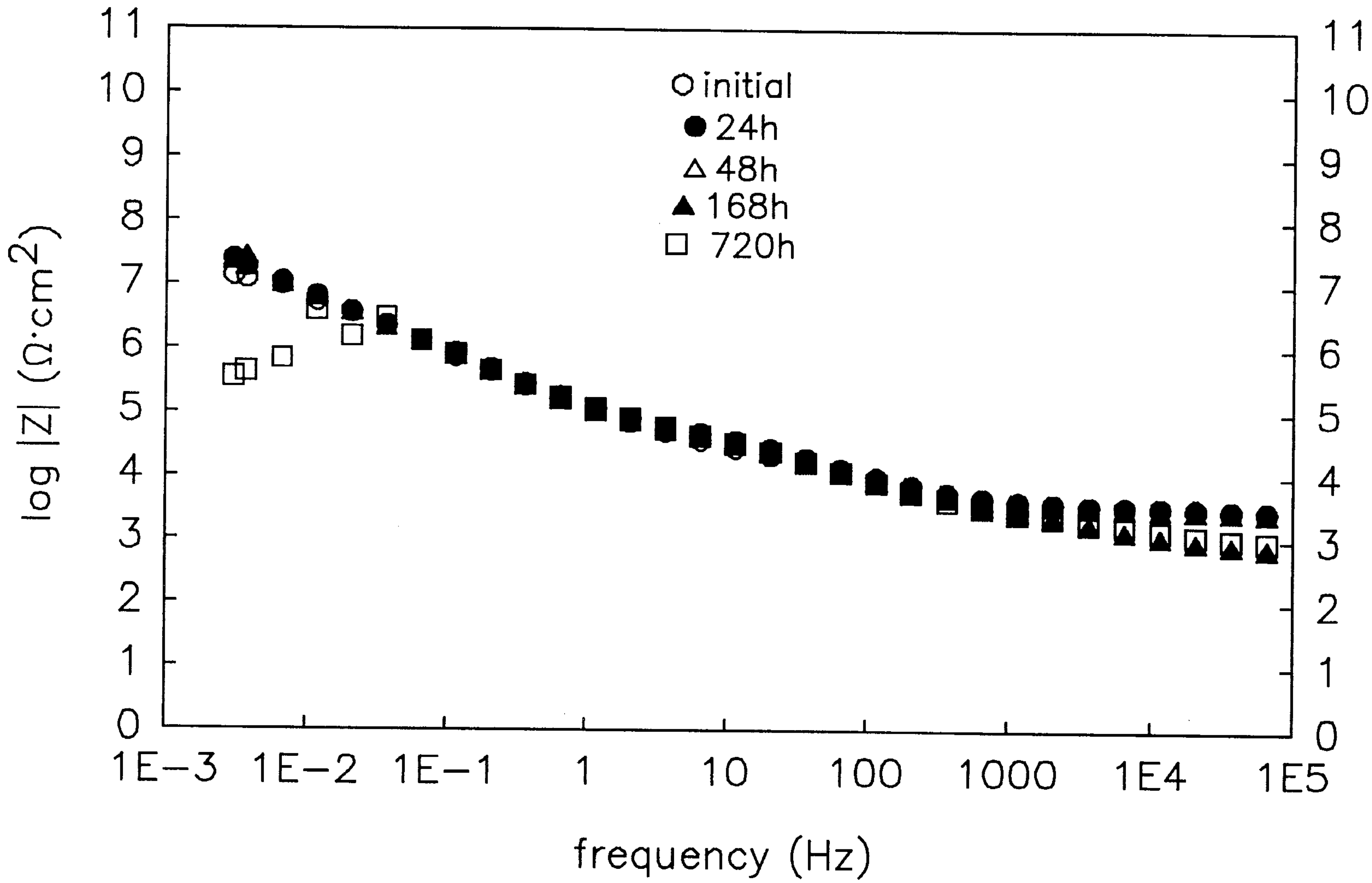

Figure 161. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al in 0.01 M K_2SO_4 + 0.003 M KCl.

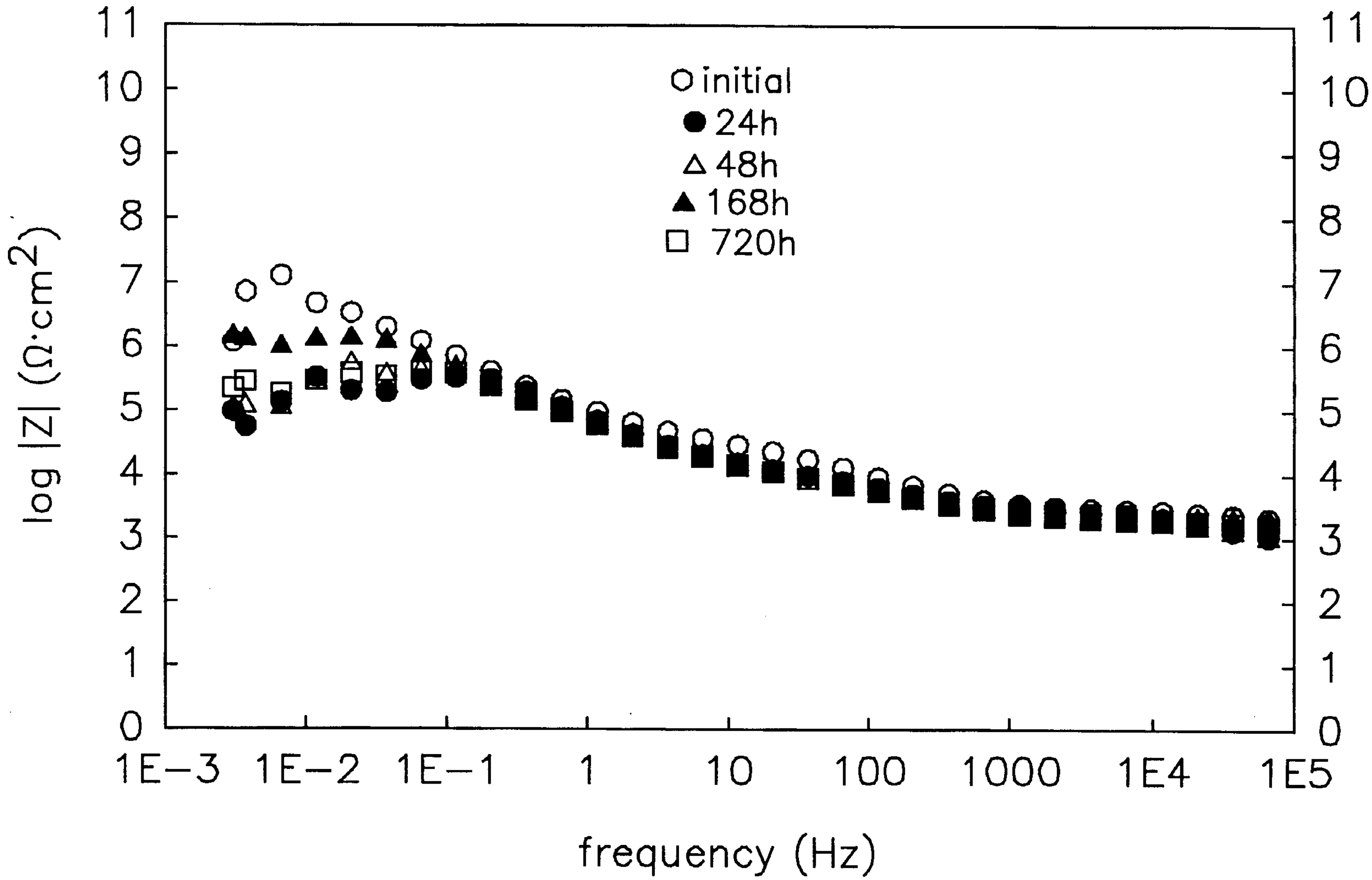

Figure 162. Impedance spectra of Epoxy 3 cured 2 h at 100°C on CCC Al with 17% MPSi in the coating in 0.01 M K_2SO_4 + 0.003 M KCl.

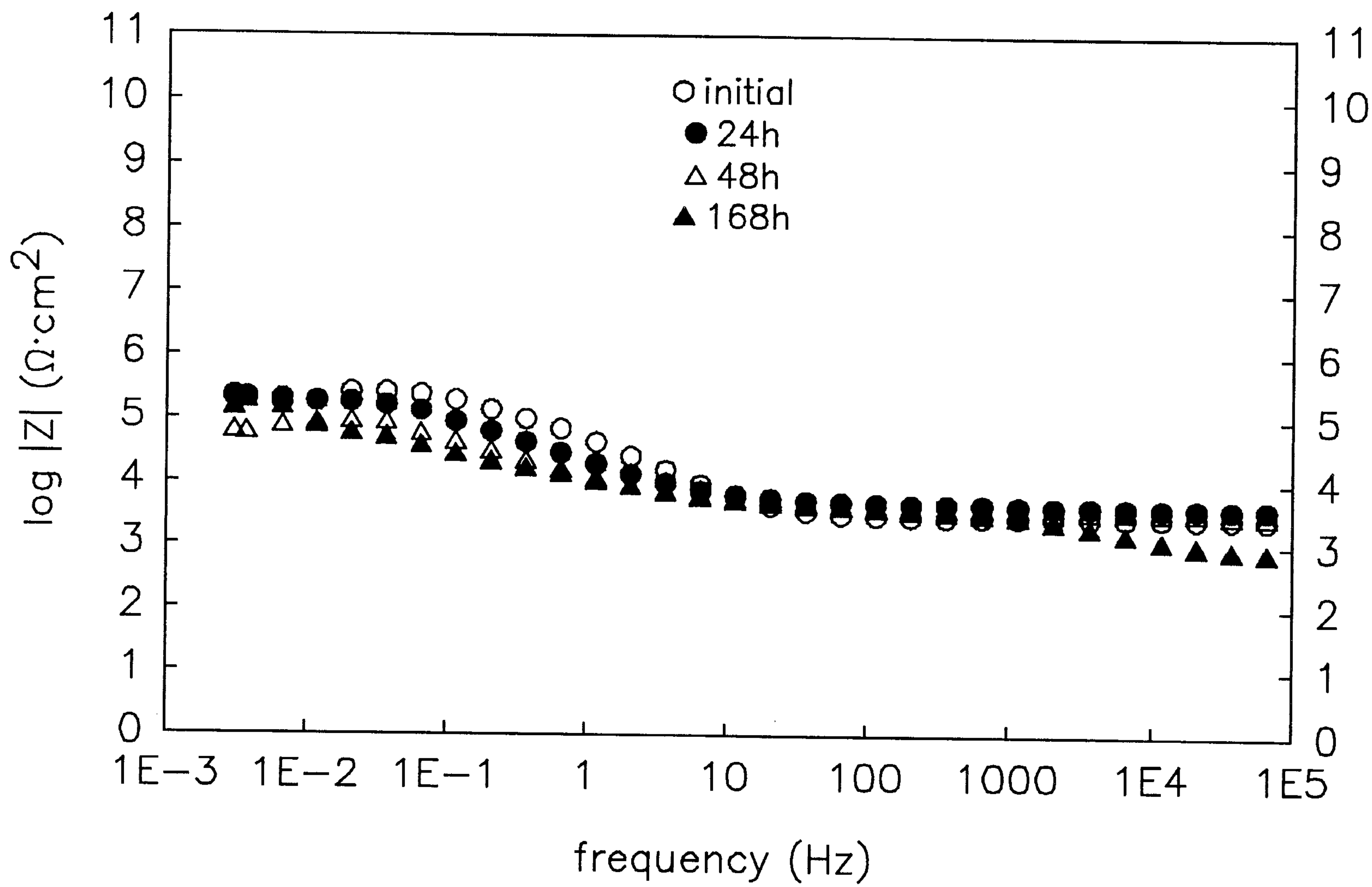

Figure 163. Impedance spectra of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al with in 0.01 M K_2SO_4 (trial 1).

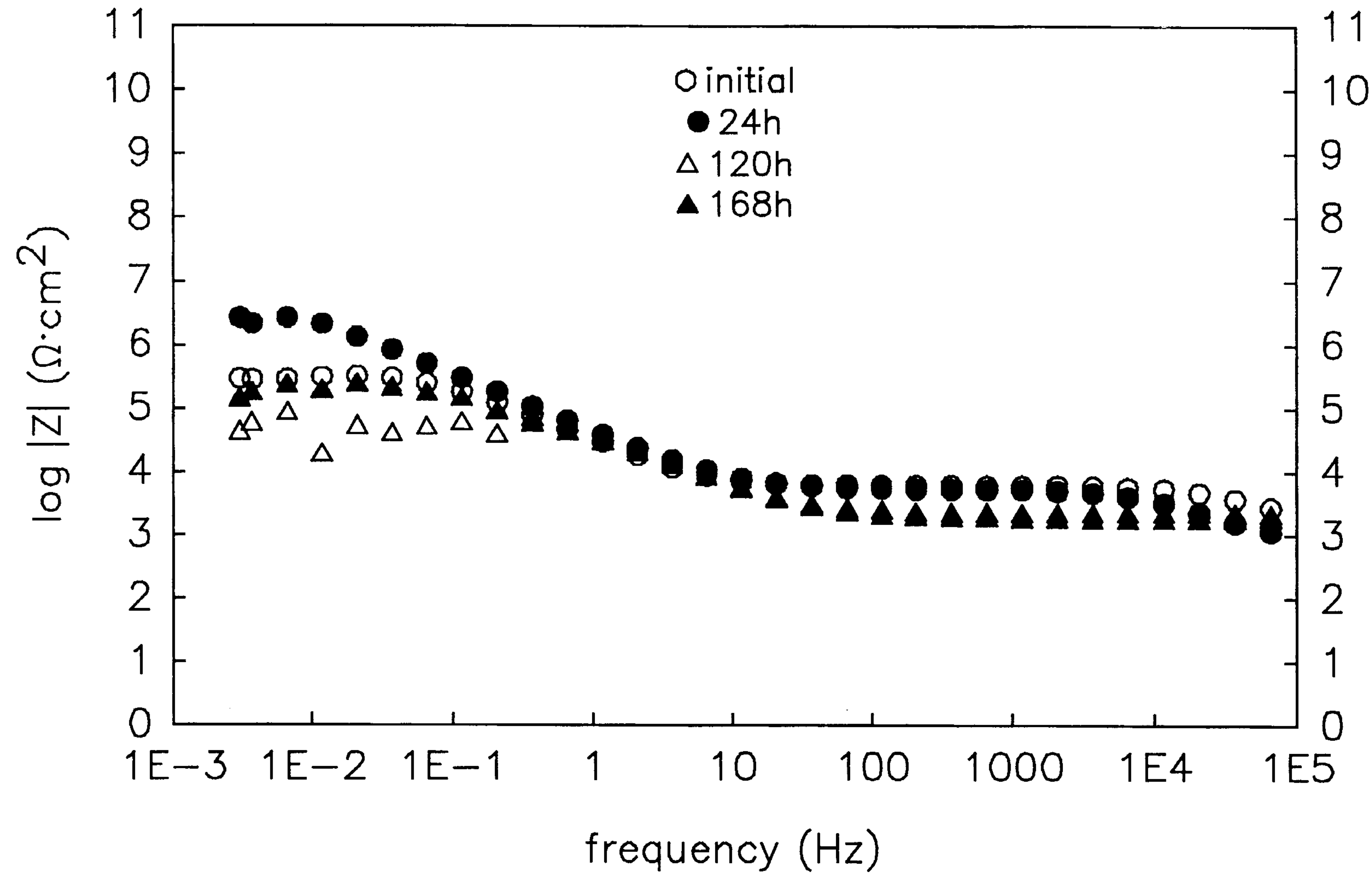

Figure 164. Impedance spectra of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al in 0.01 M K_2SO_4 (trial 2).

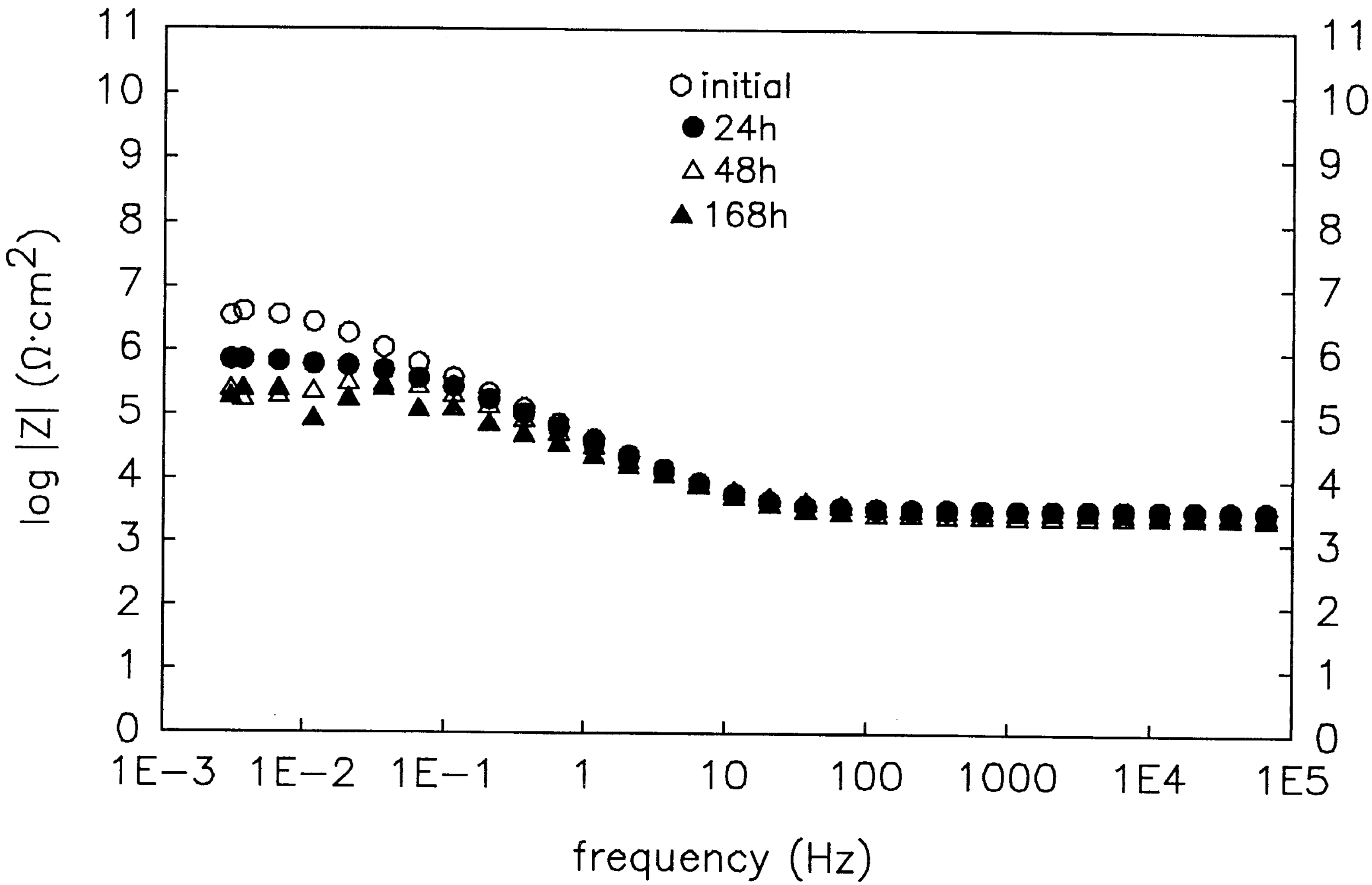

Figure 165. Impedance spectra of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al with 17% MPSi in the coating in 0.01 M K_2SO_4 (trial 1).

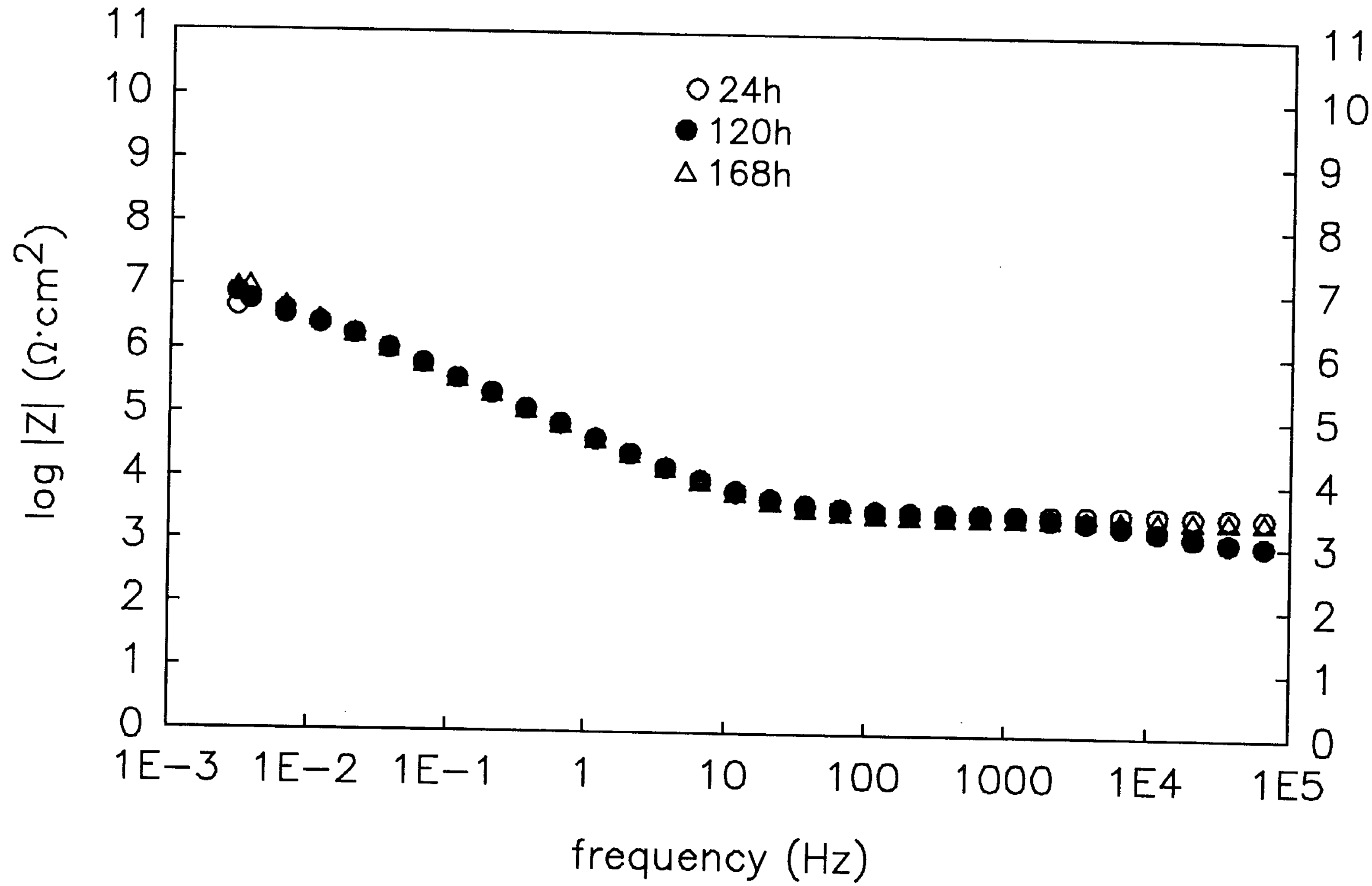

Figure 166. Impedance spectra of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al with 17% MPSi in the coating in 0.01 M K_2SO_4 (trial 2).

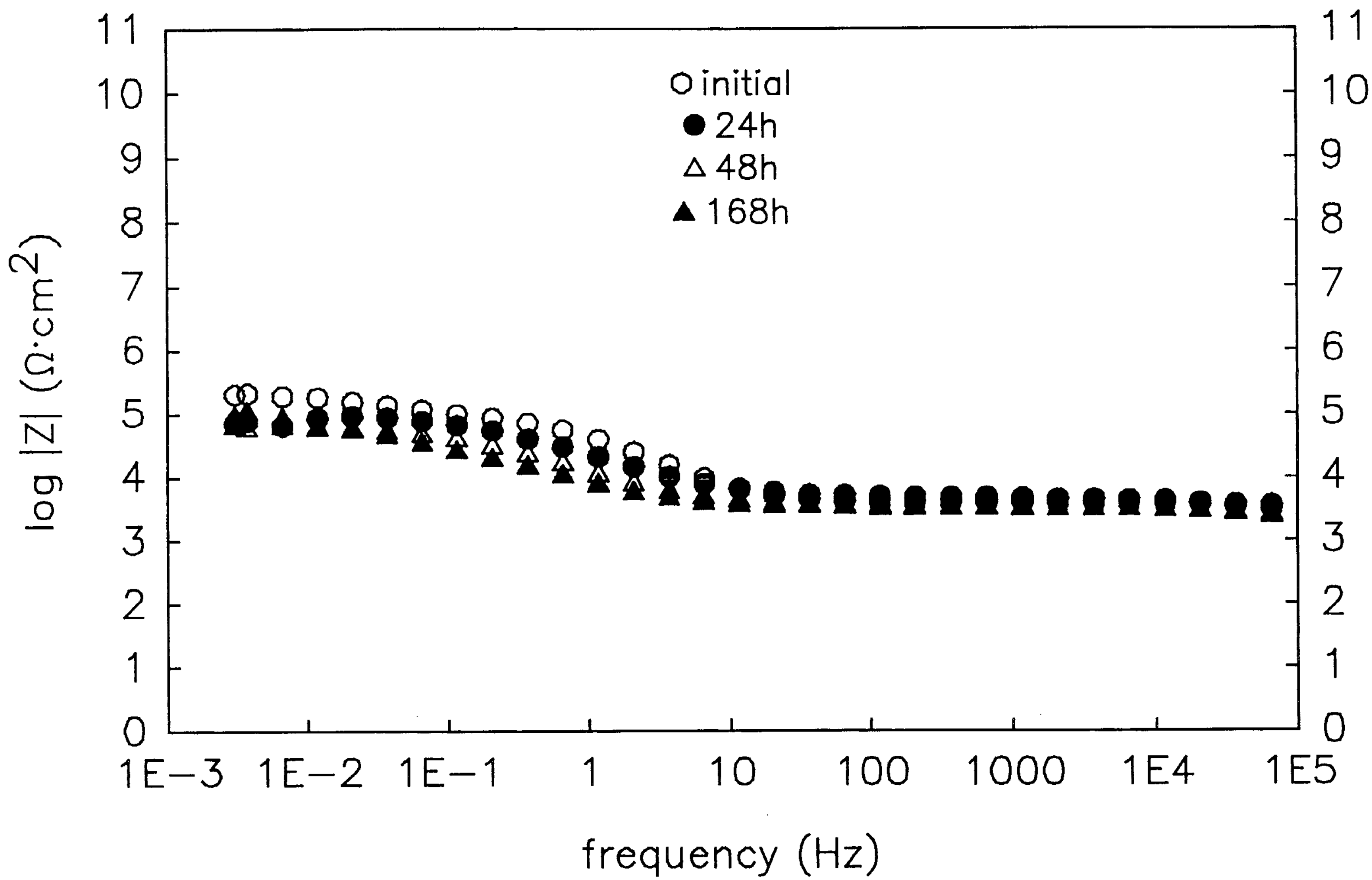

Figure 167. Impedance spectra of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al with 17% BaBor in the coating in 0.01 M K_2SO_4 (trial 1).

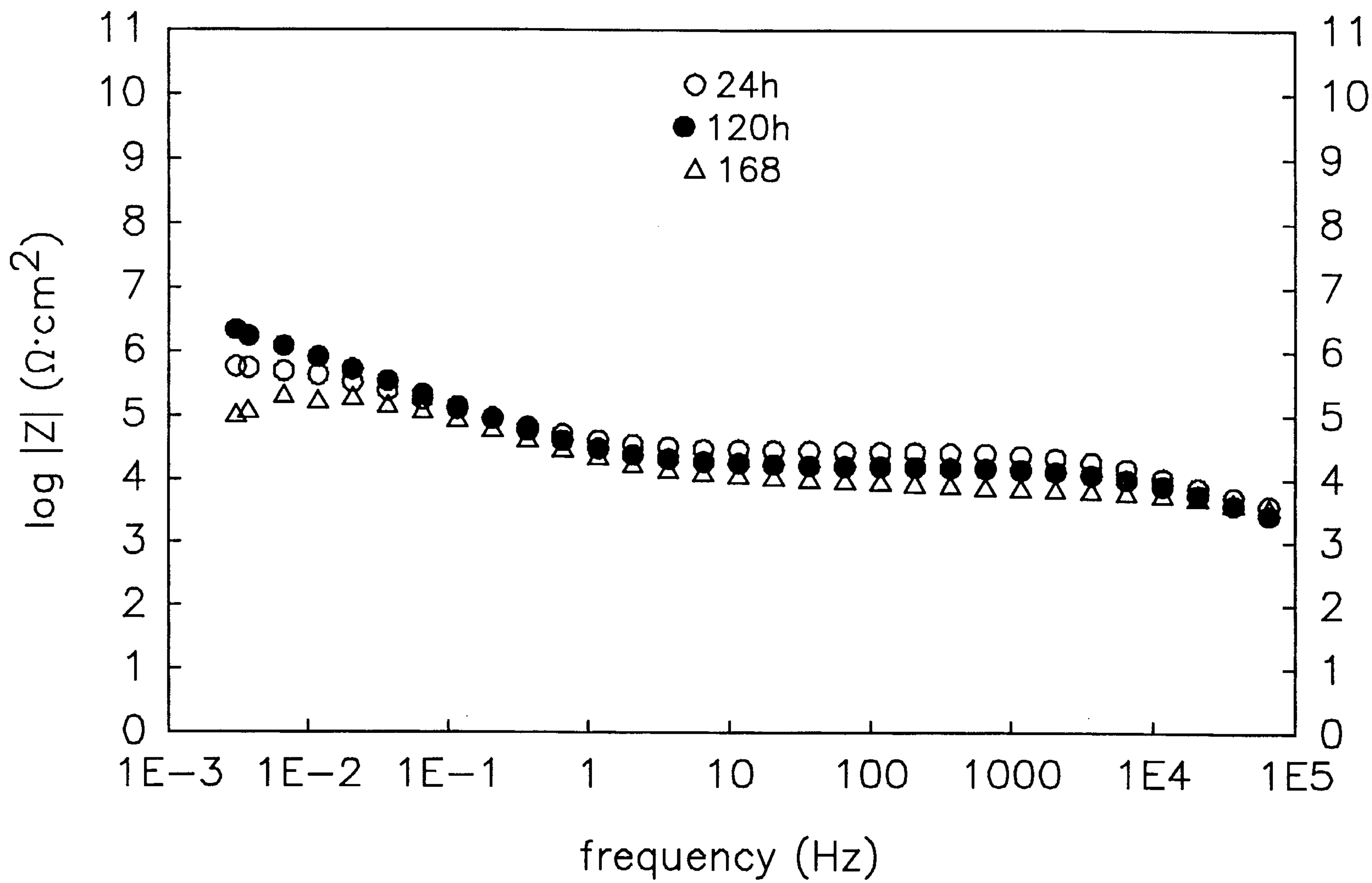

Figure 168. Impedance spectra of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al with 17% BaBor in the coating in 0.01 M K_2SO_4 (trial 2).

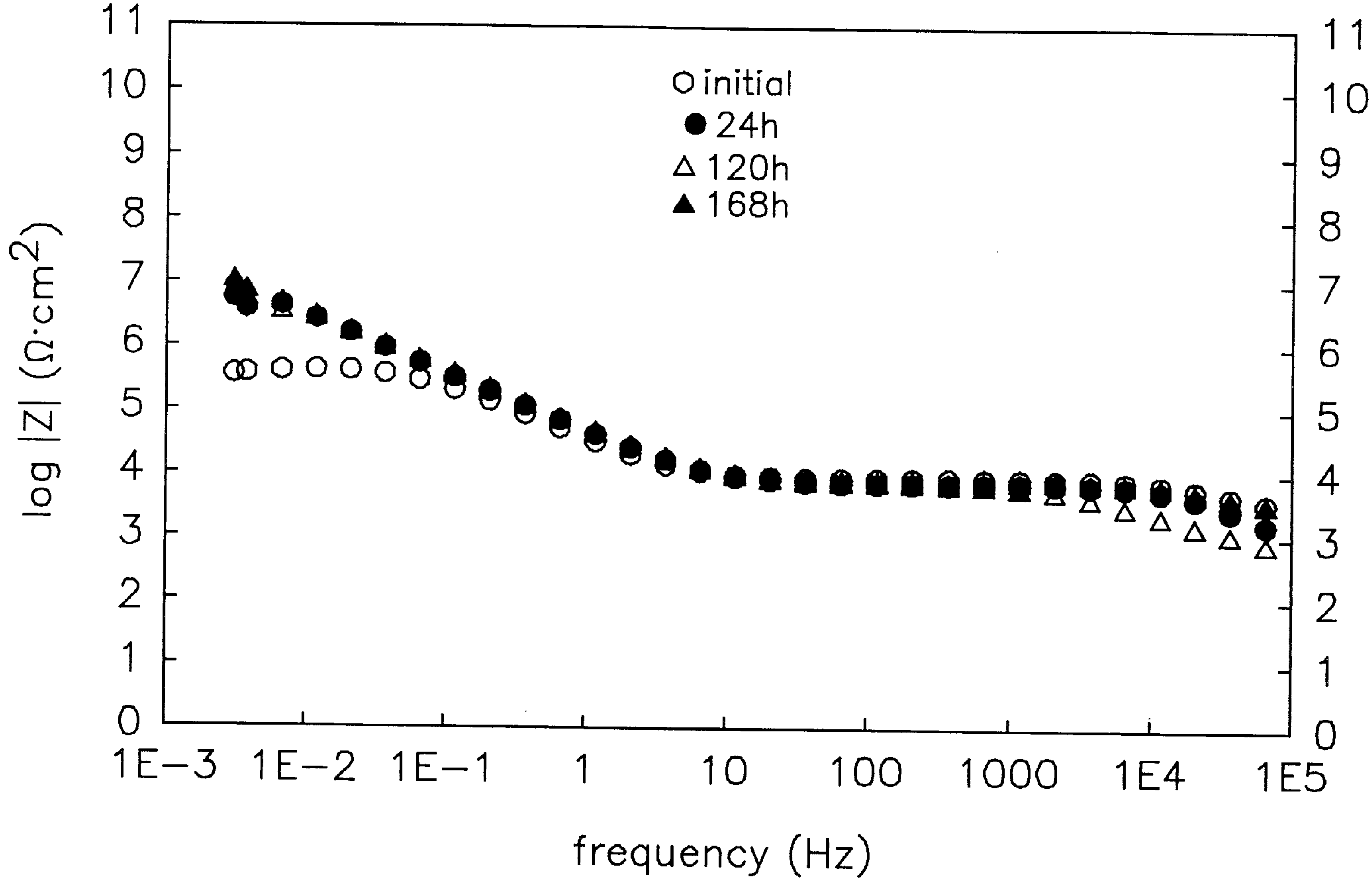

Figure 169. Impedance spectra of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al in MPSi saturated 0.01 M K_2SO_4.

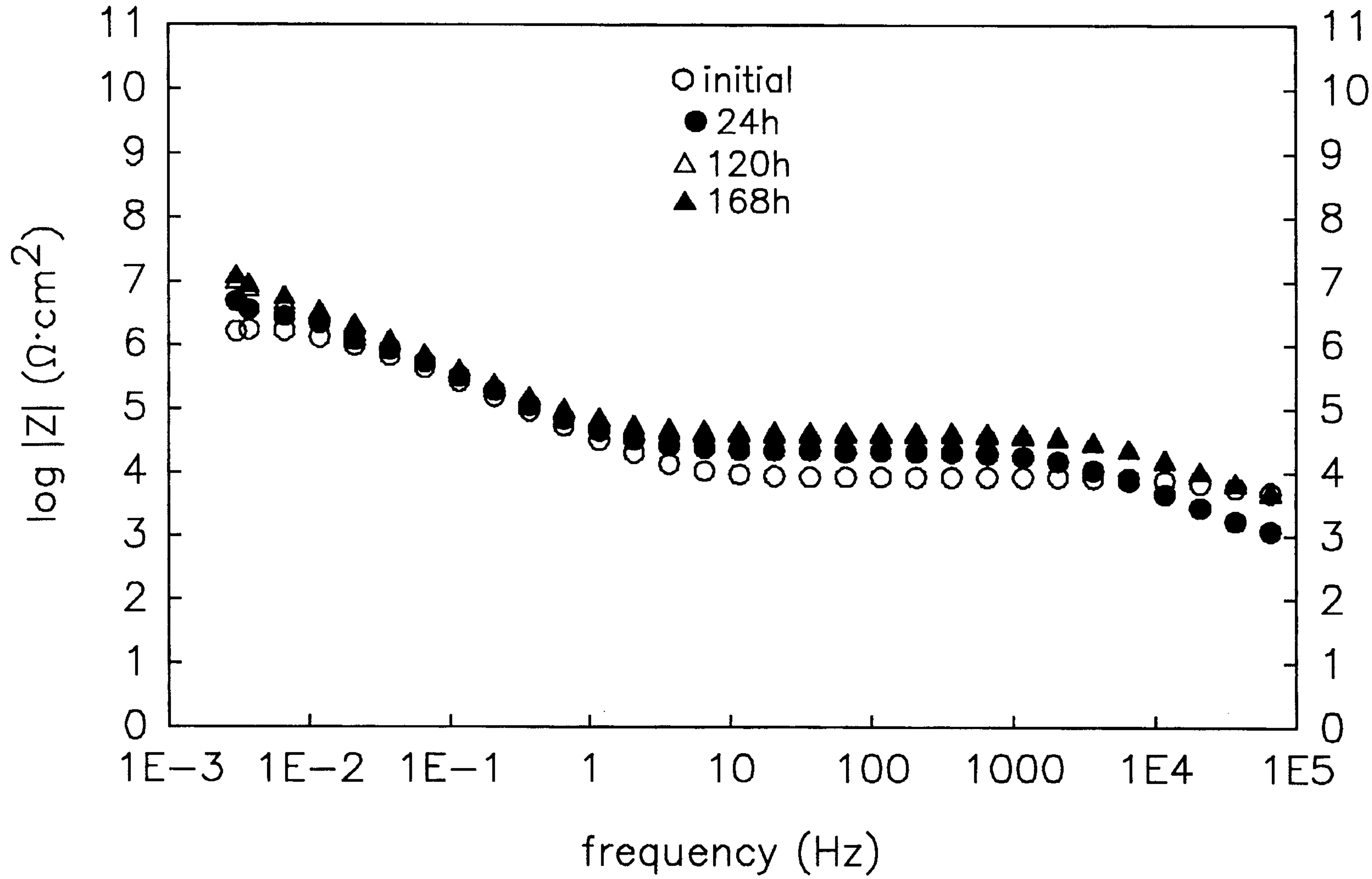

Figure 170. Impedance spectra of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al in BaBor saturated 0.01 M K_2SO_4.

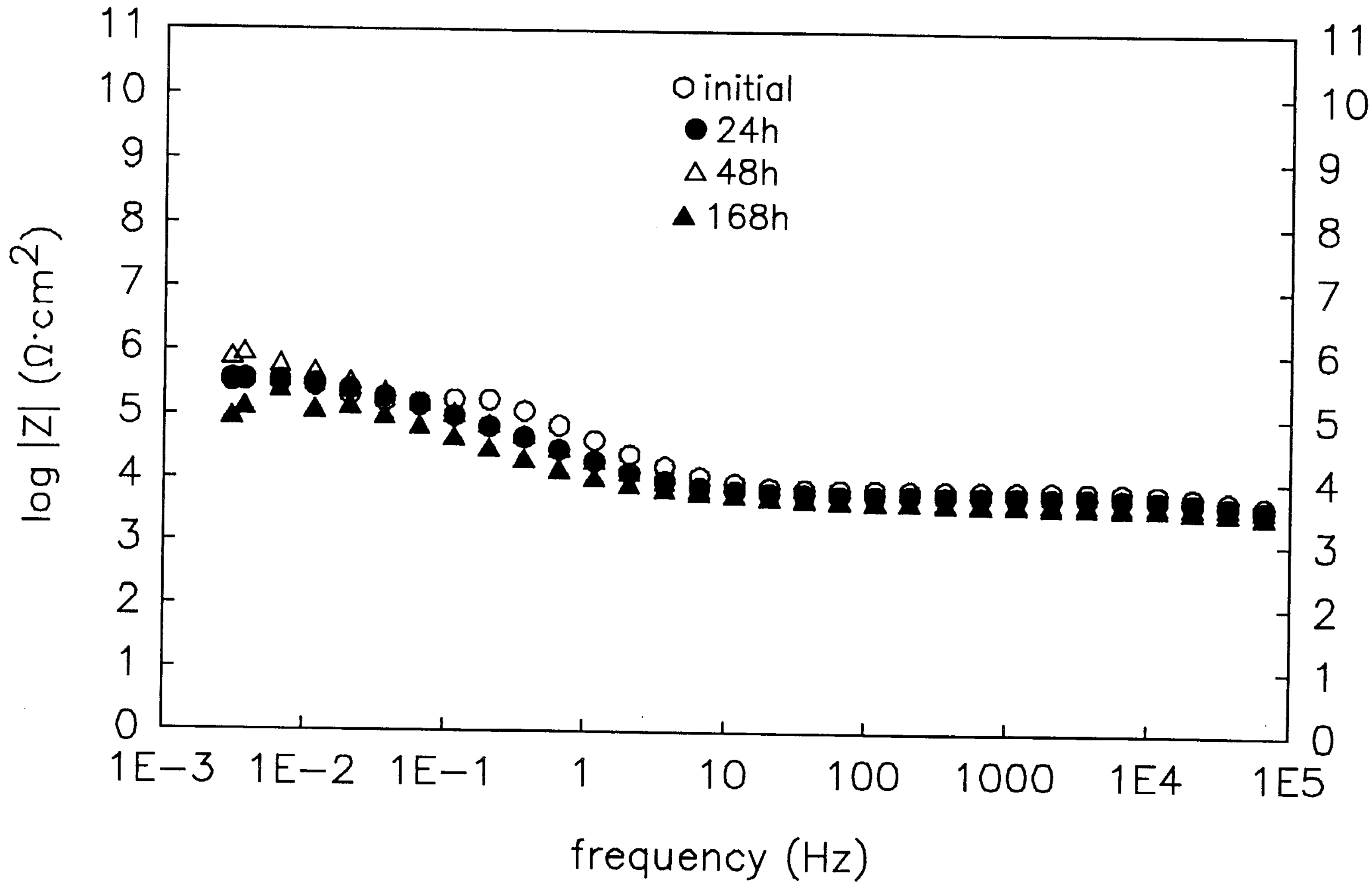

Figure 171. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al in 0.01 M K_2SO_4 (trial 1).

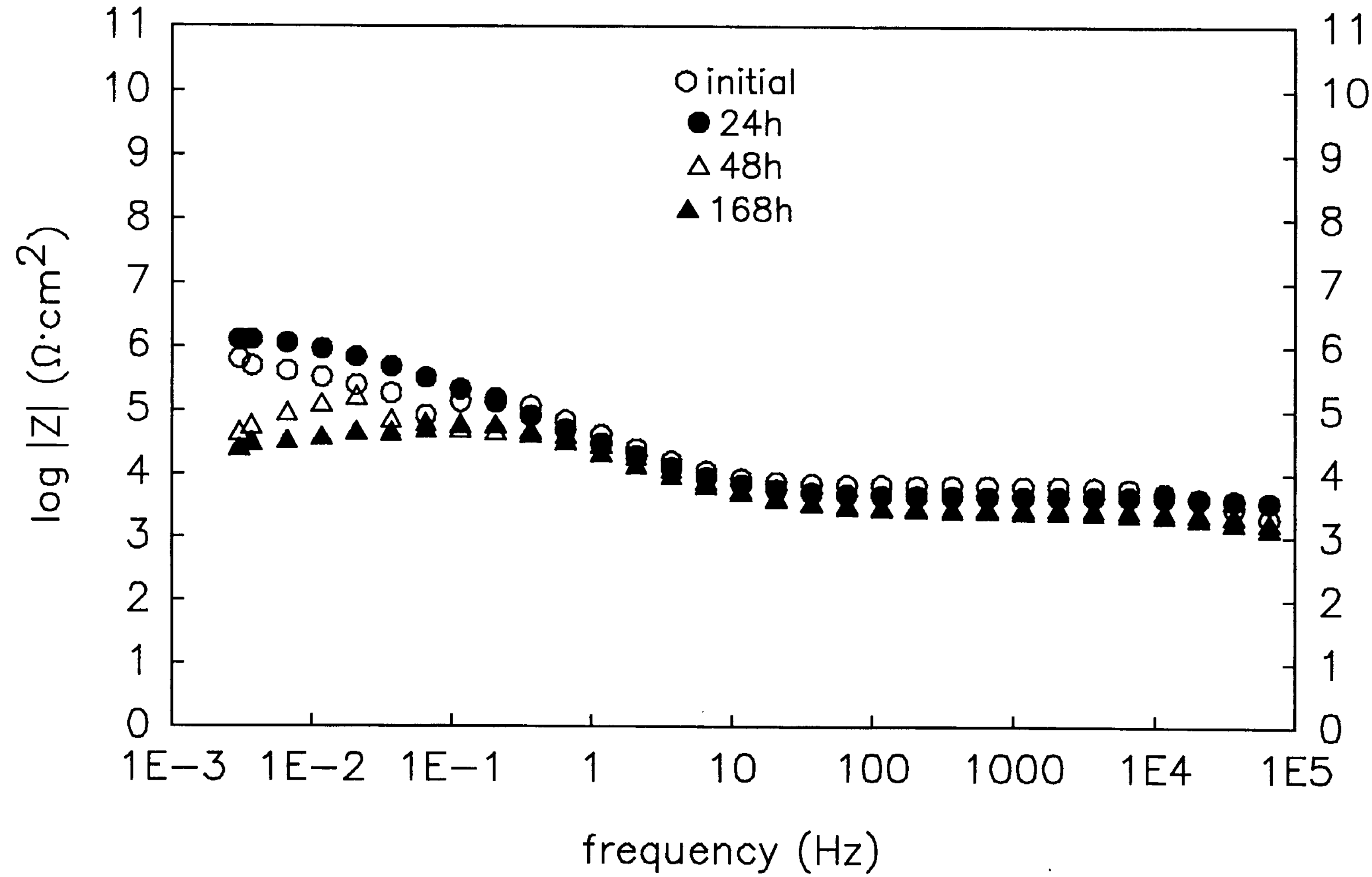

Figure 172. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al in 0.01 M K_2SO_4 (trial 2).

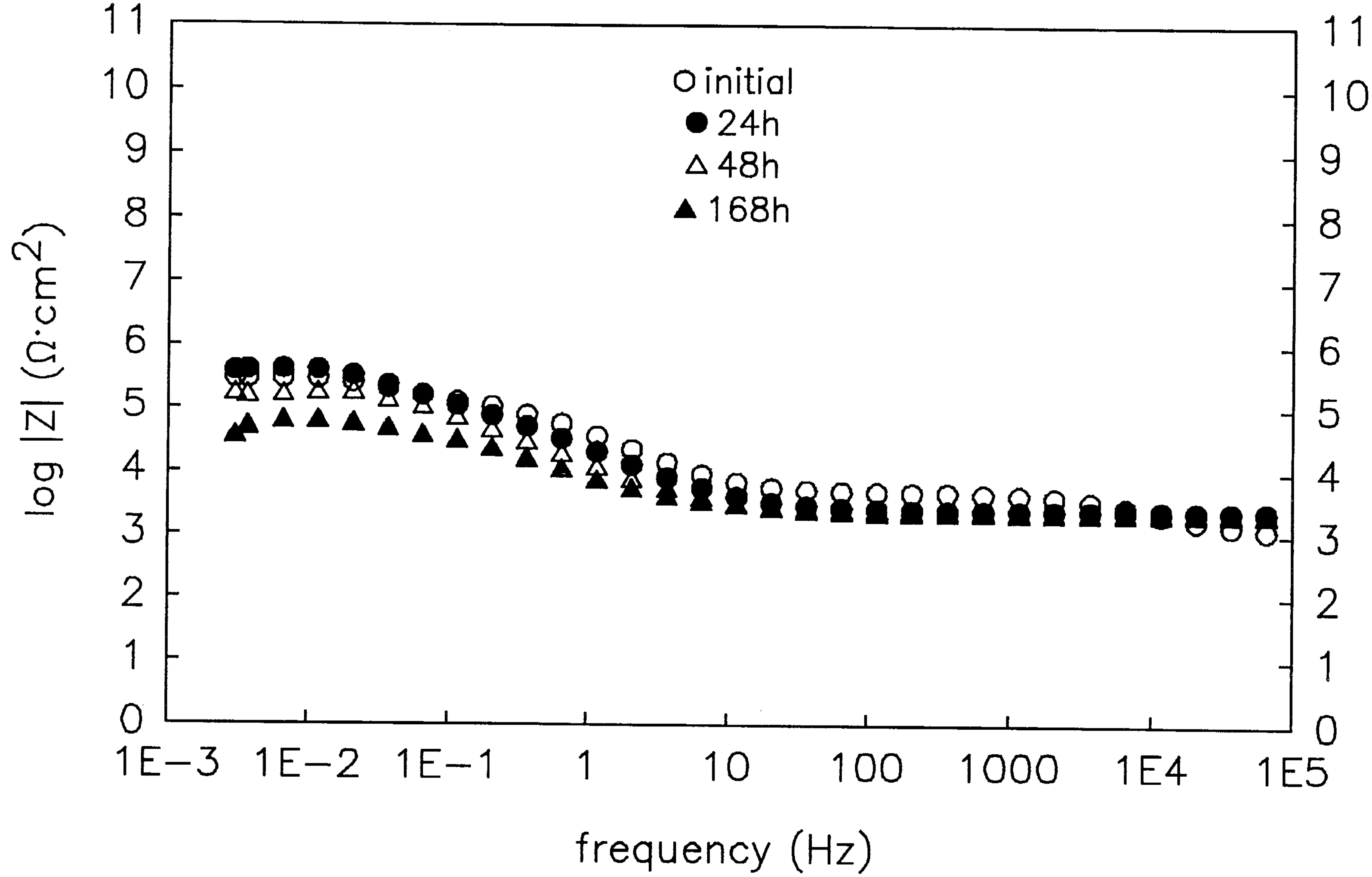

Figure 173. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al in 0.01 M K_2SO_4 (trial 3).

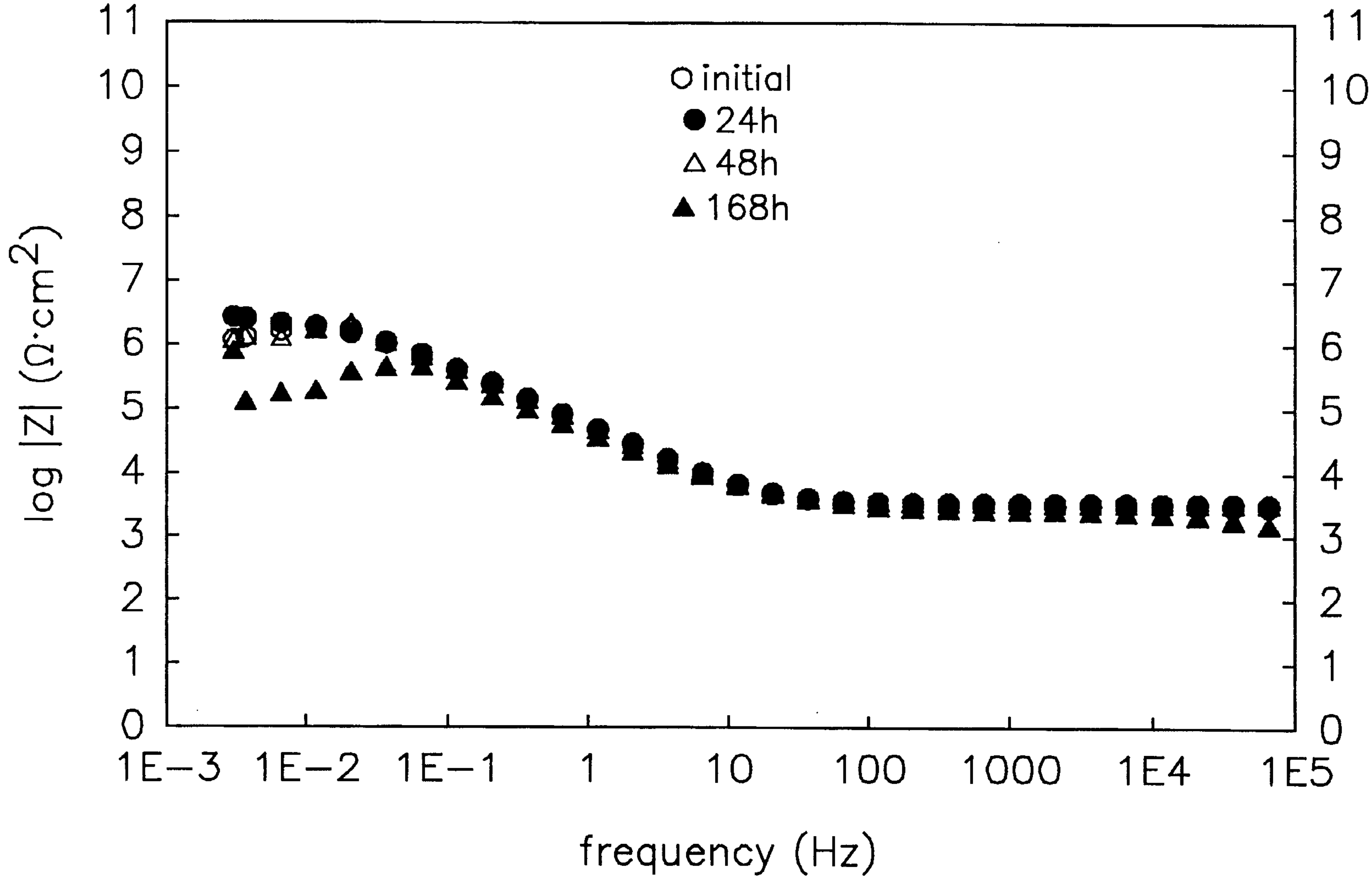

Figure 174. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al with 17% MPSi in the coating in 0.01 M K_2SO_4 (trial 1).

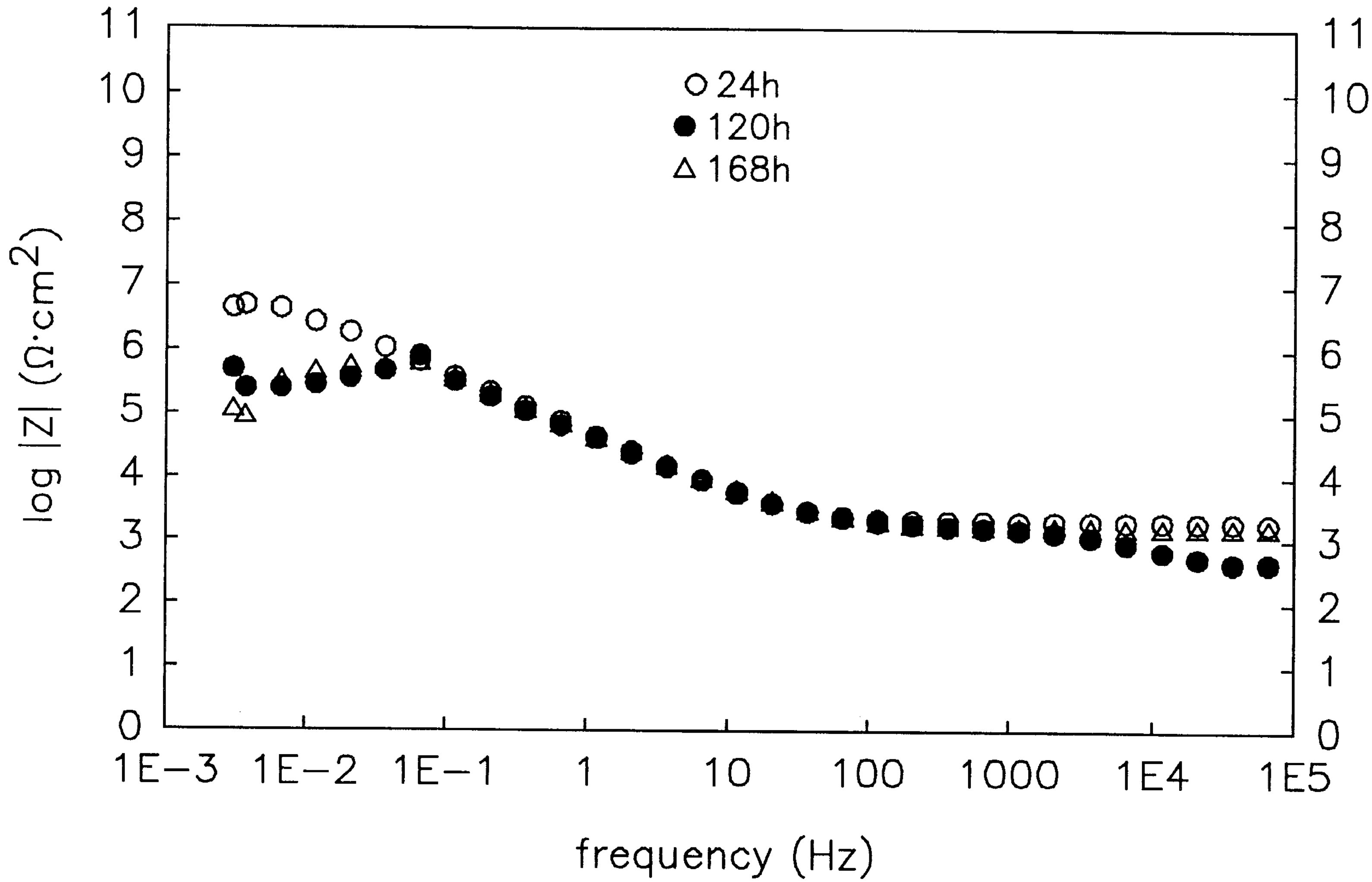

Figure 175. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al with 17% MPSi in the coating in 0.01 M K_2SO_4 (trial 2).

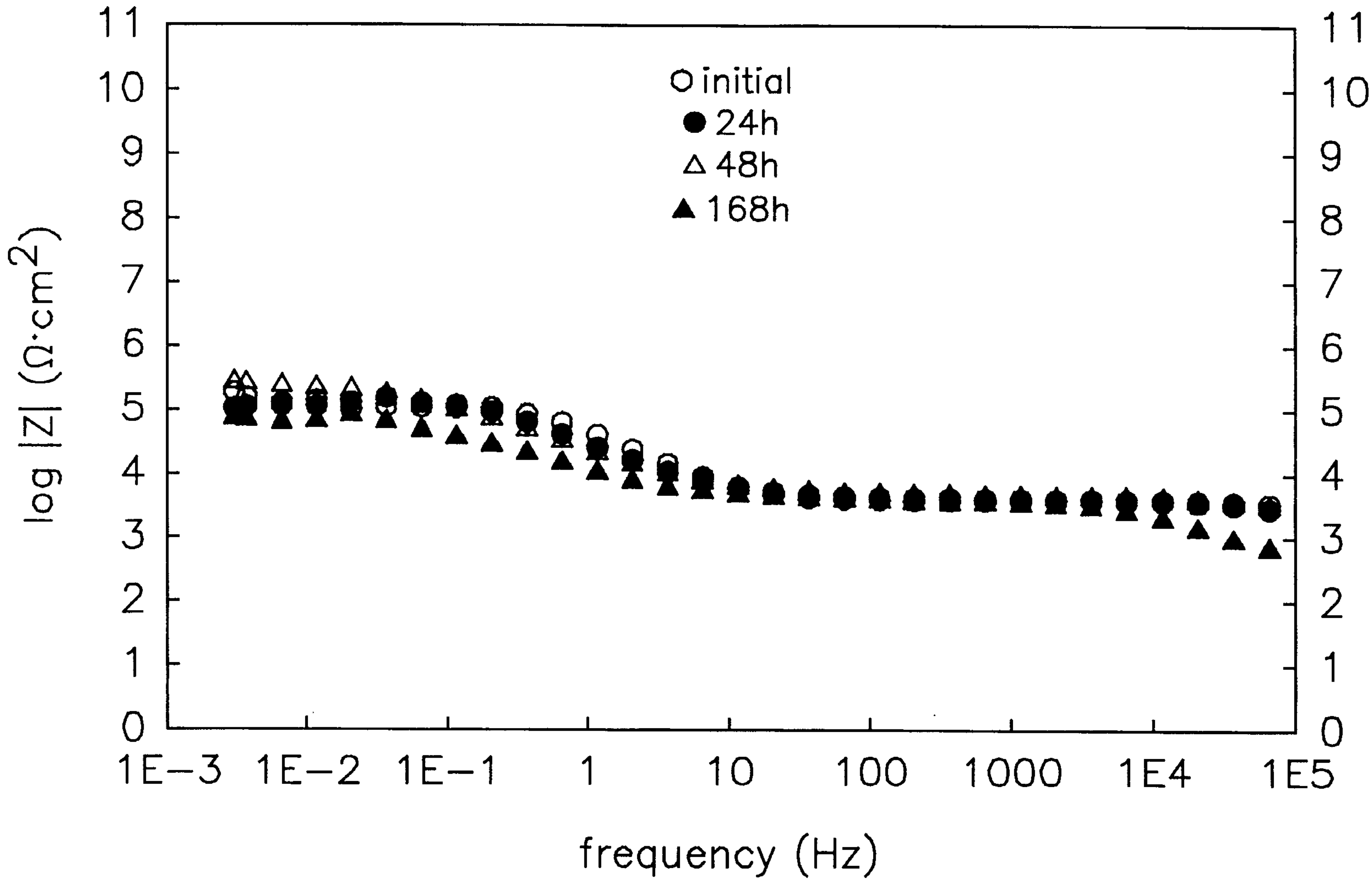

Figure 176. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al with 17% BaBor in the coating in 0.01 M K_2SO_4 (trial 1).

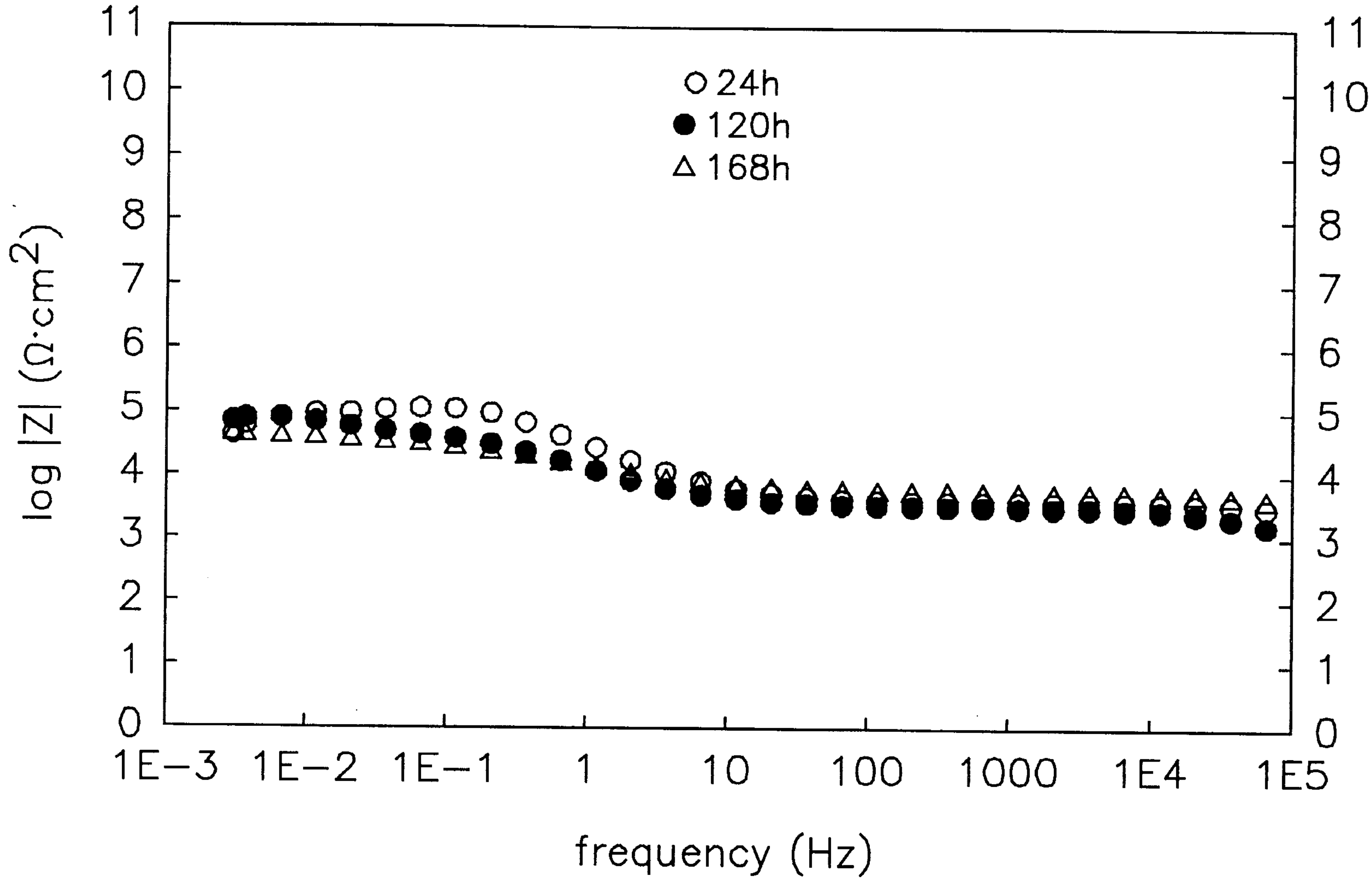

Figure 177. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al with 17% BaBor in the coating in 0.01 M K_2SO_4 (trial 2).

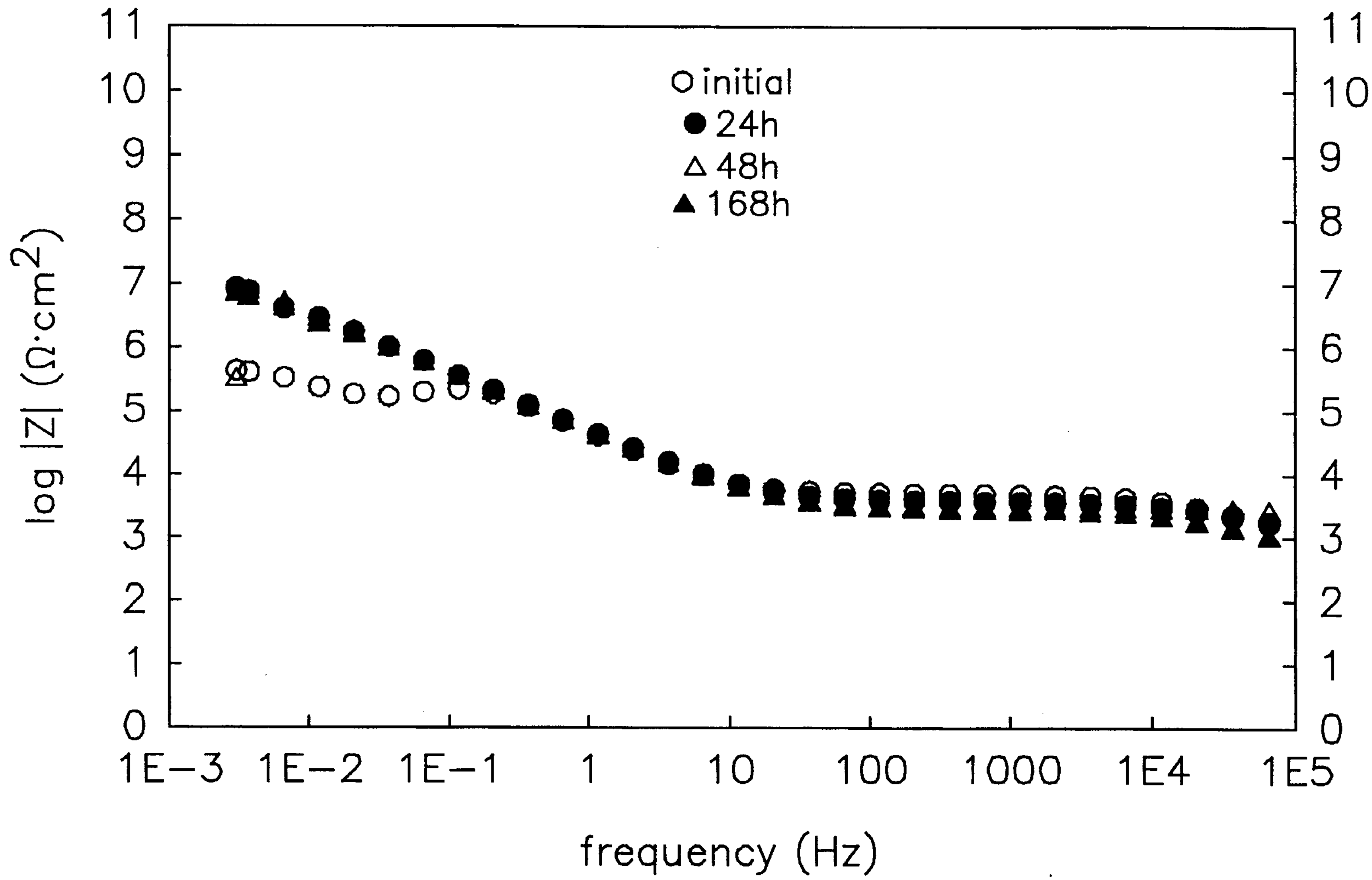

Figure 178. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al in MPSi saturated 0.01 M K_2SO_4 (trial 1).

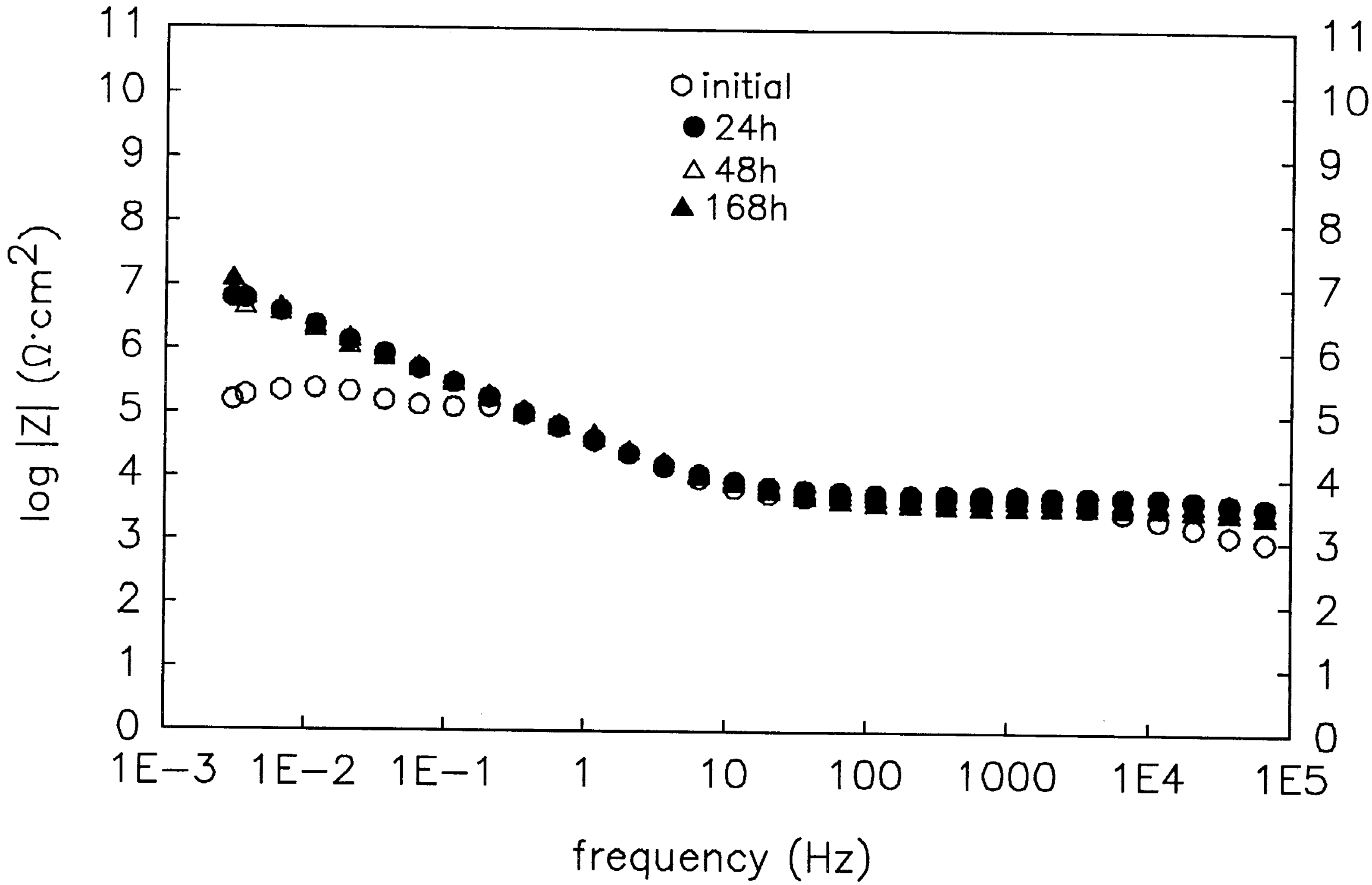

Figure 179. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al in MPSi saturated 0.01 M K_2SO_4 (trial 2).

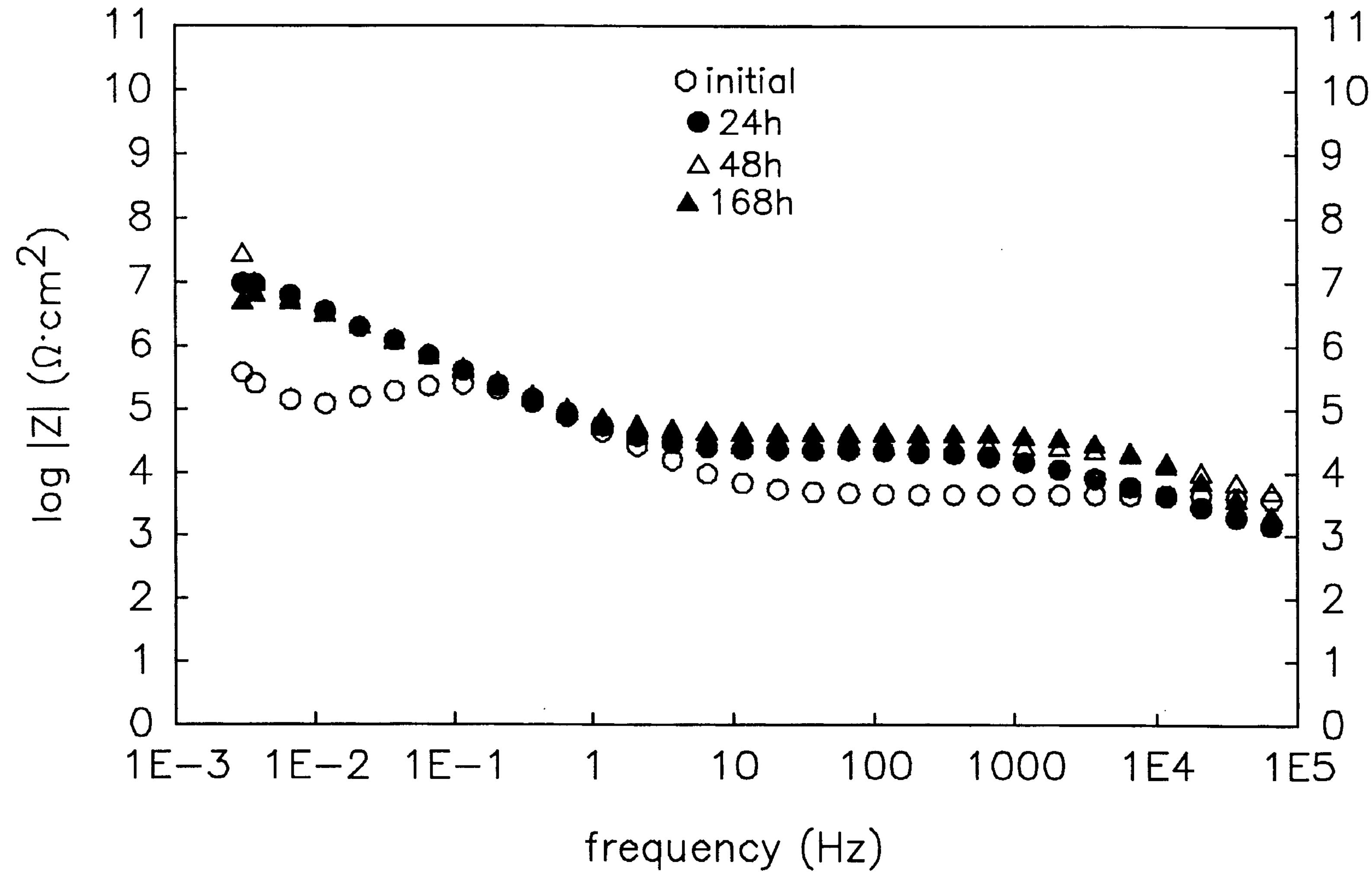

Figure 180. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al BaBor saturated 0.01 M K_2SO_4 (trial 1).

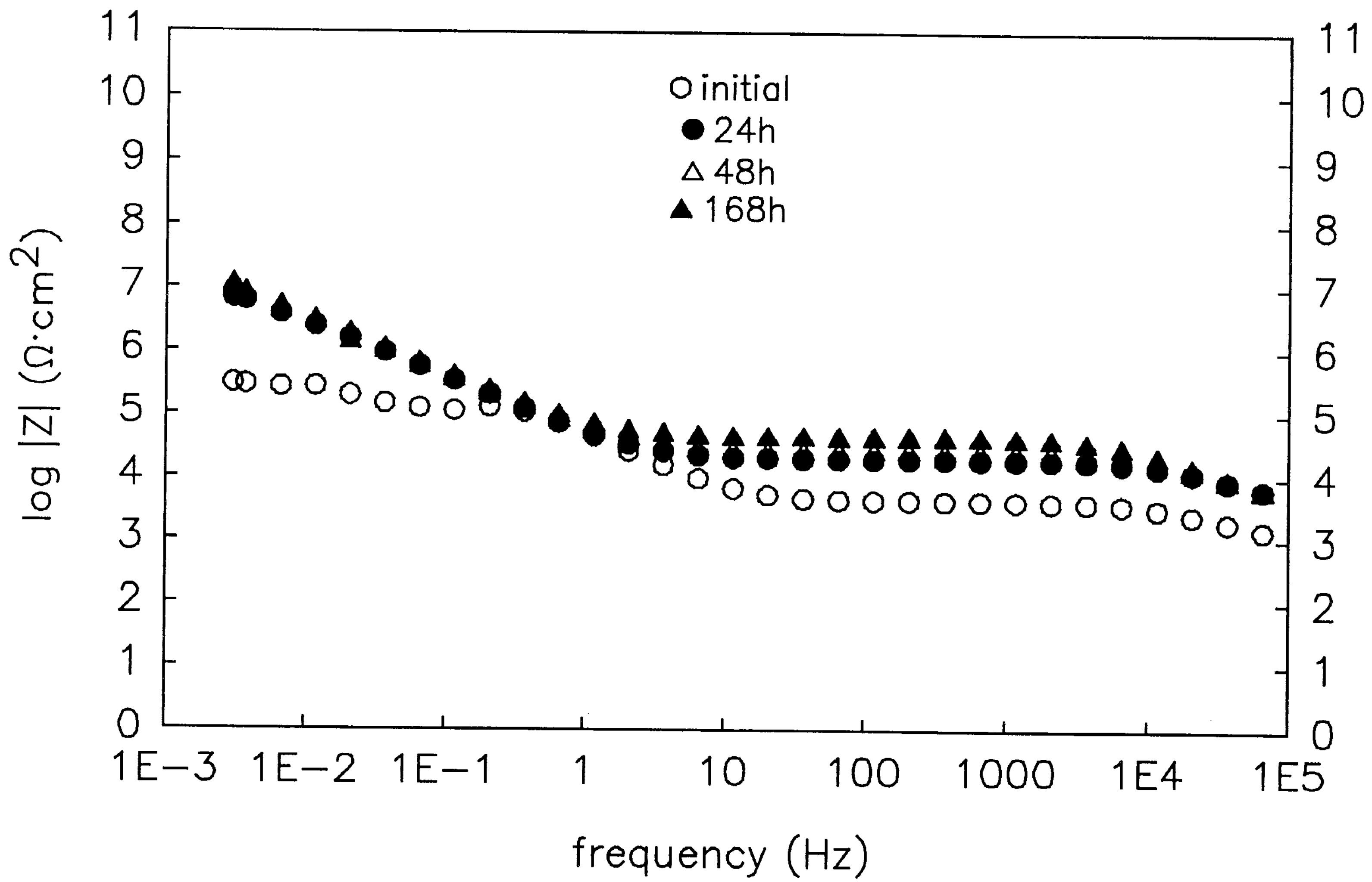

Figure 181. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al in BaBor saturated 0.01 M K_2SO_4 (trial 2).

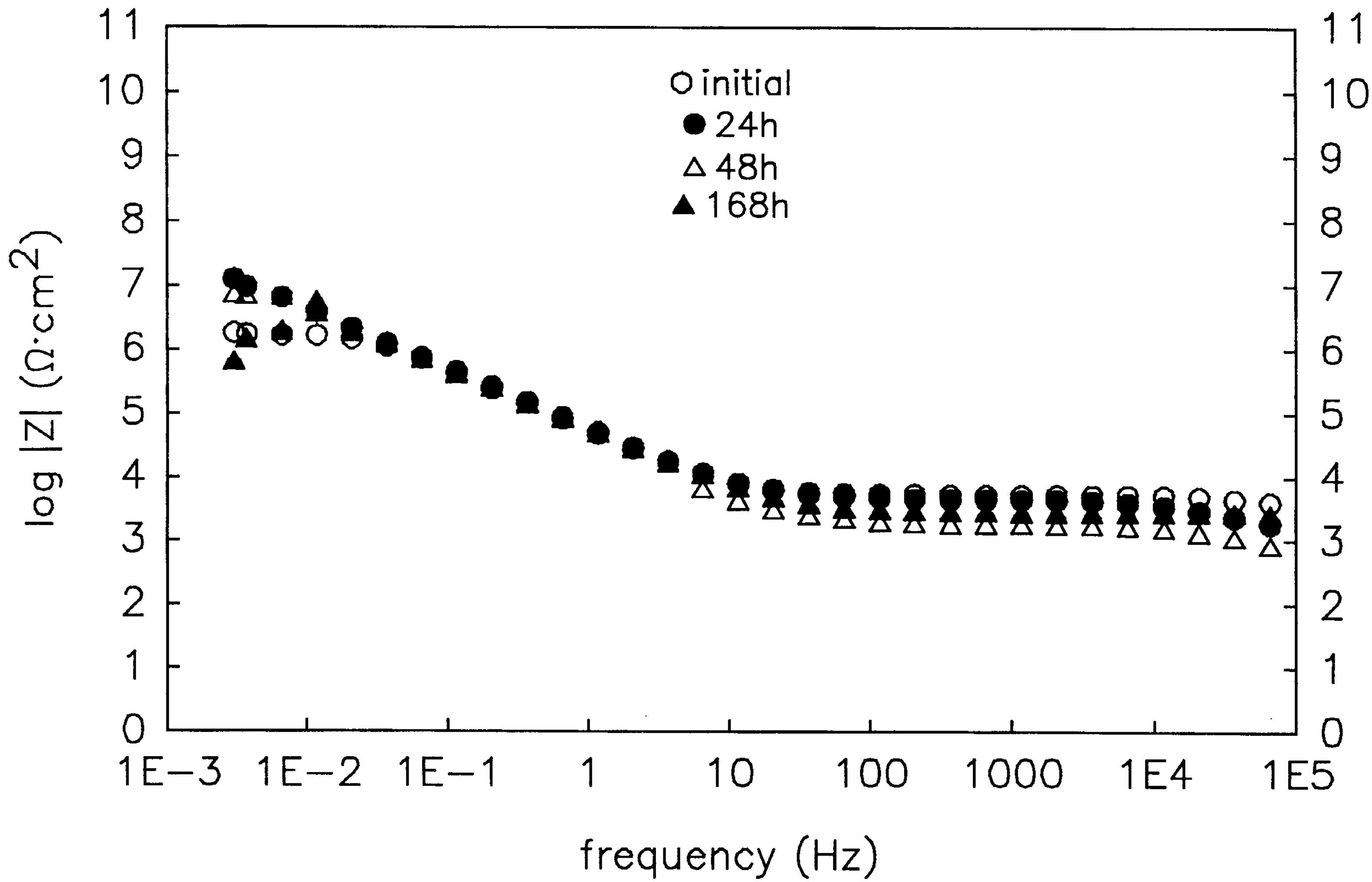

Figure 182. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al with 17% MPSi in the coating in MPSi saturated 0.01 M K_2SO_4.

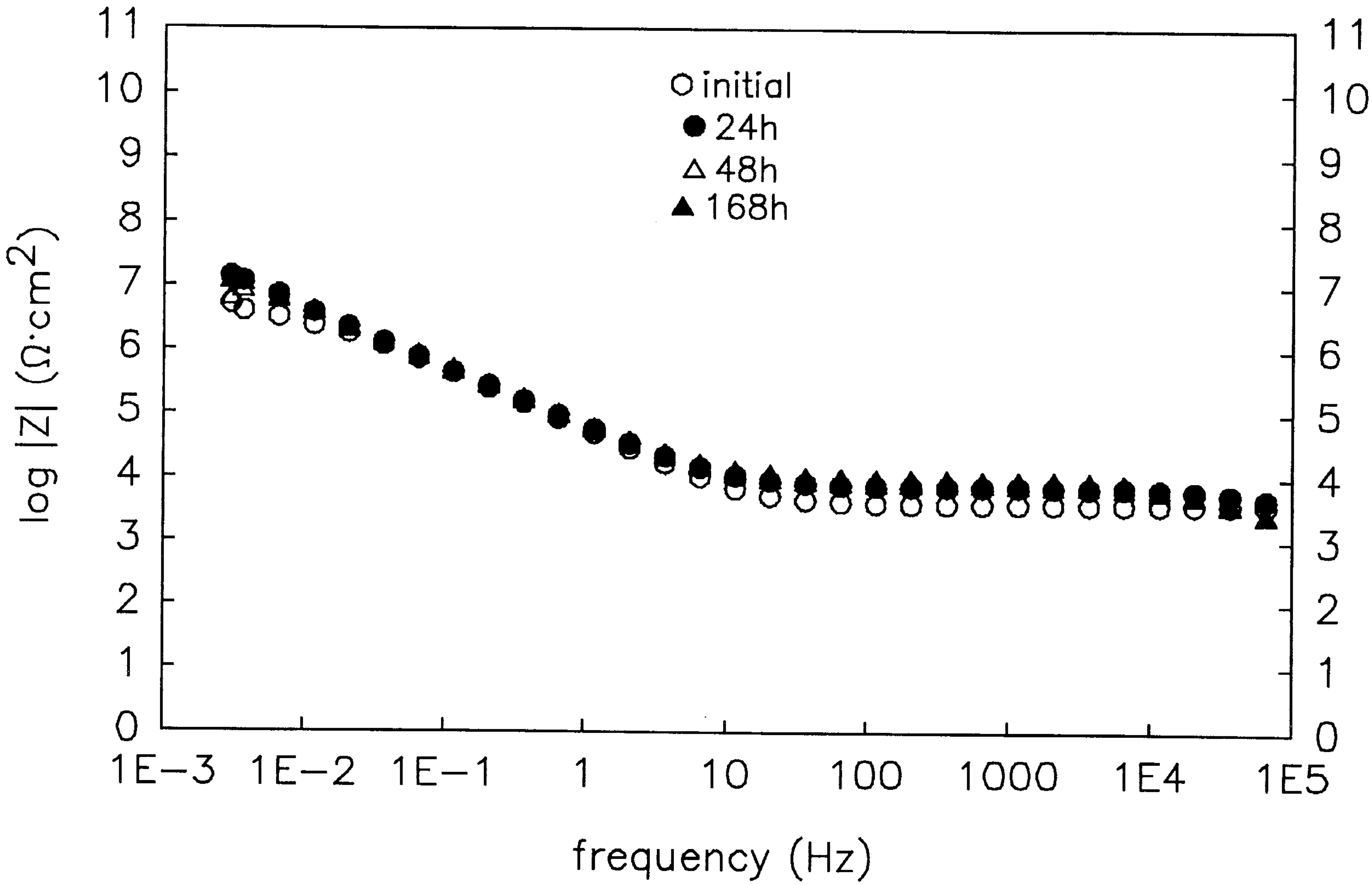

Figure 183. Impedance spectra of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al with 17% BaBor in the coating in BaBor saturated 0.01 M K_2SO_4.

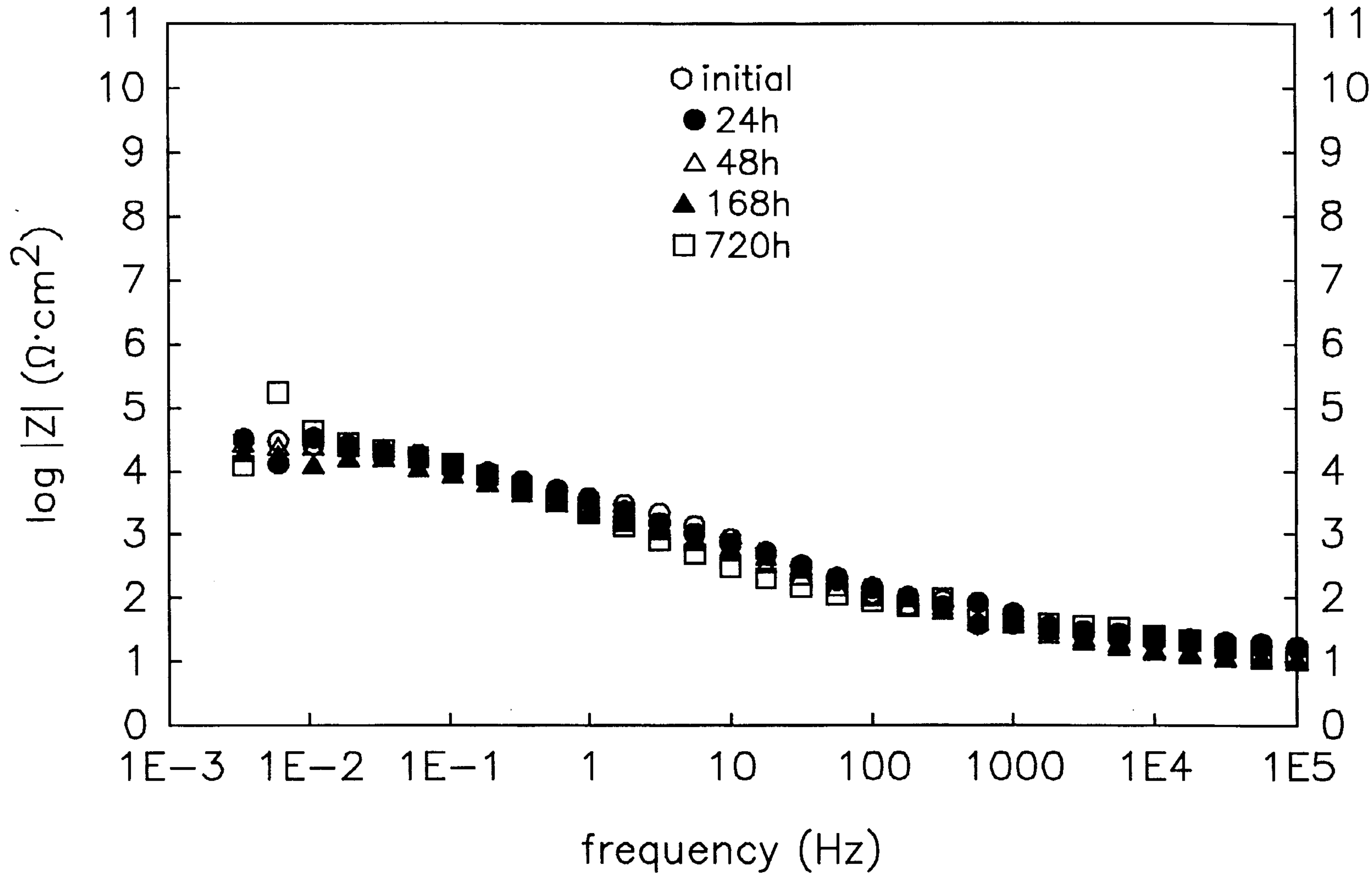

Figure 184. Impedance spectra of Epoxy 1 cured 7 days at RT with an 800 μm diameter defect on CCC Al in 0.01 M K_2SO_4 + 0.003 M KCl.

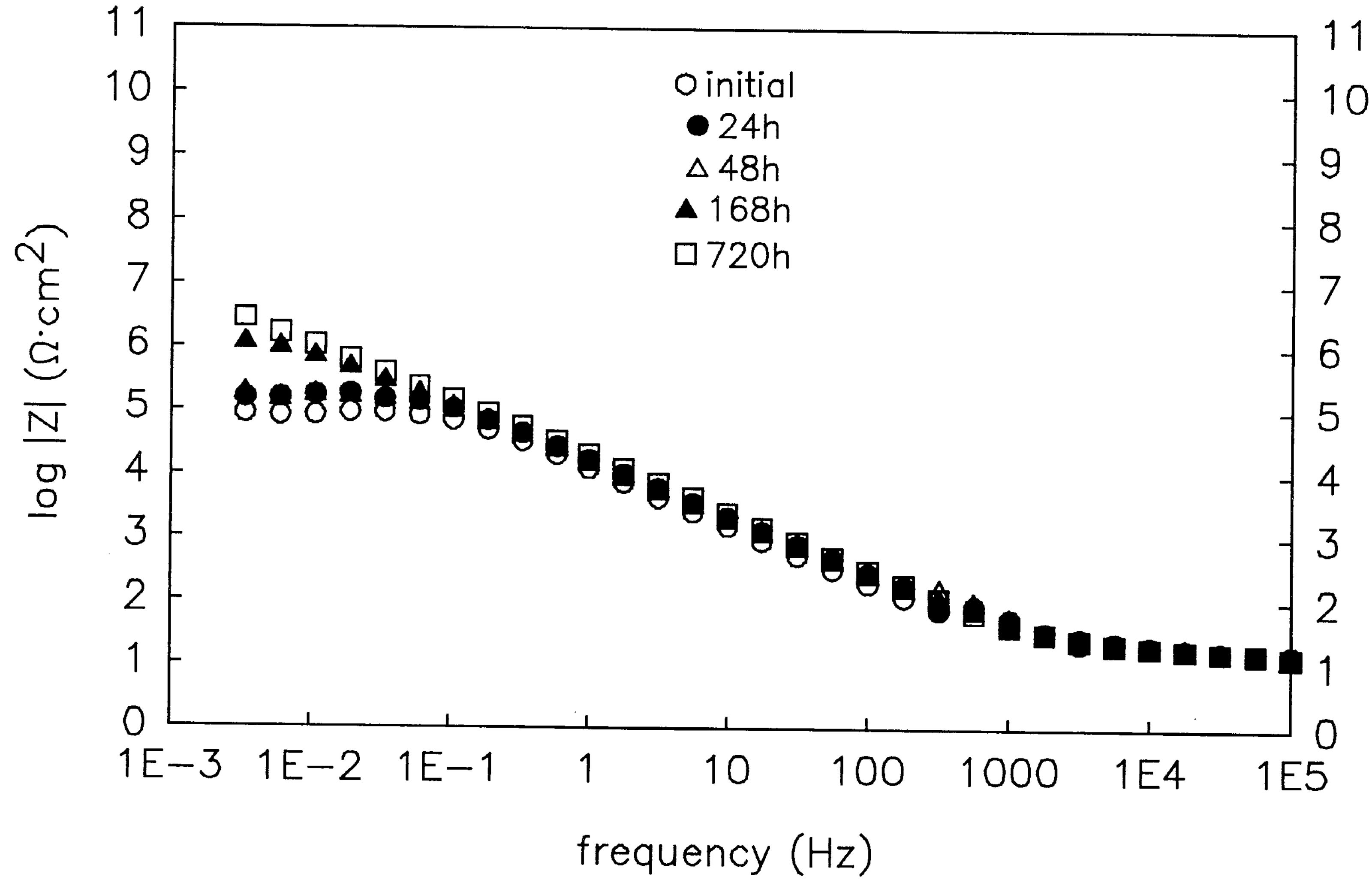

Figure 185. Impedance spectra of Epoxy 1 cured 7 d at RT with an 800 µm diameter defect on CCC Al in MPSi saturated 0.01 M K_2SO_4 + 0.003 M KCl.

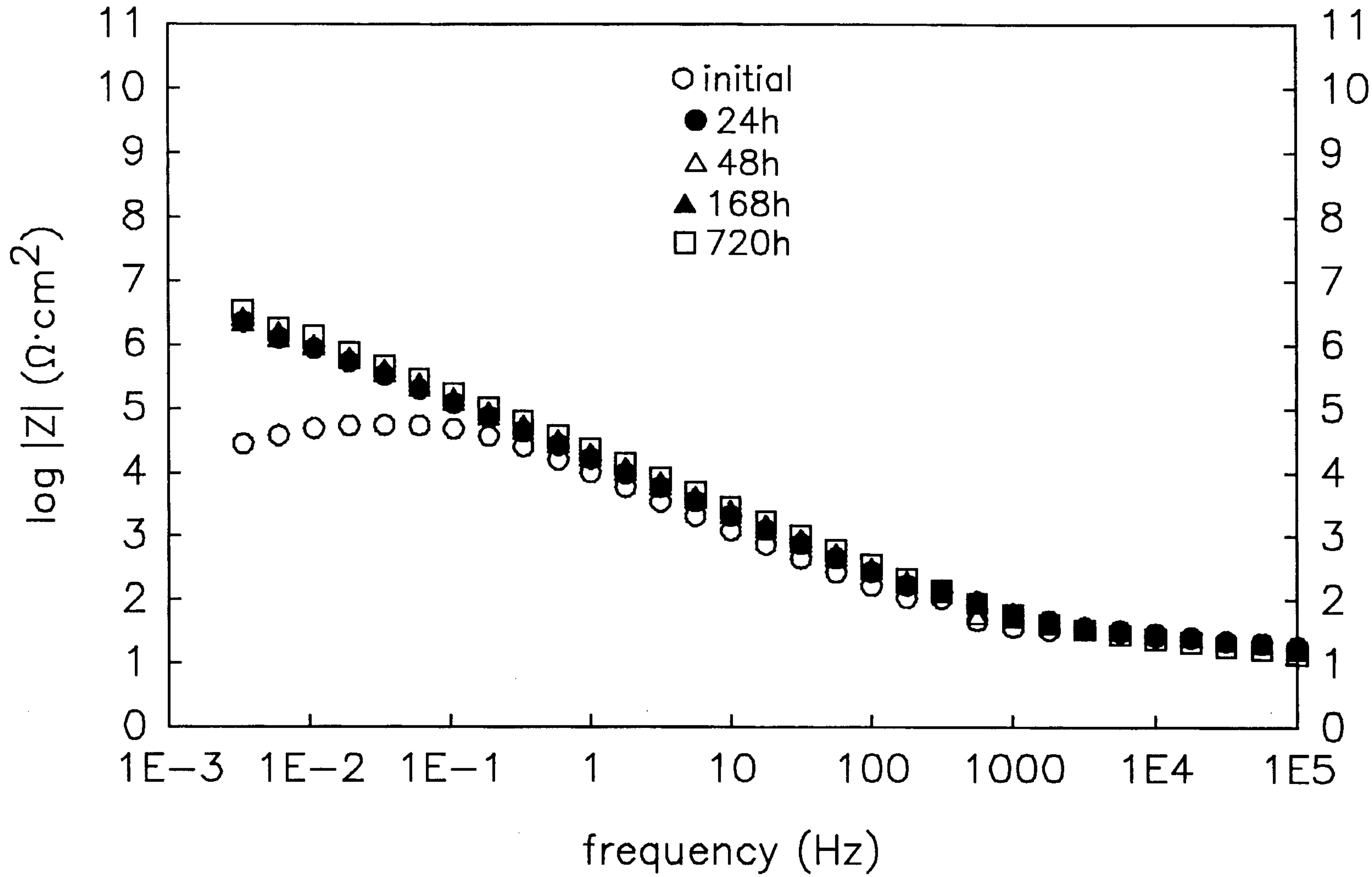

Figure 186. Impedance spectra of Epoxy 1 cured 7 days at RT with an 800 μm diameter defect on CCC Al in BaBor saturated 0.01 M K_2SO_4 + 0.003 M KCl.

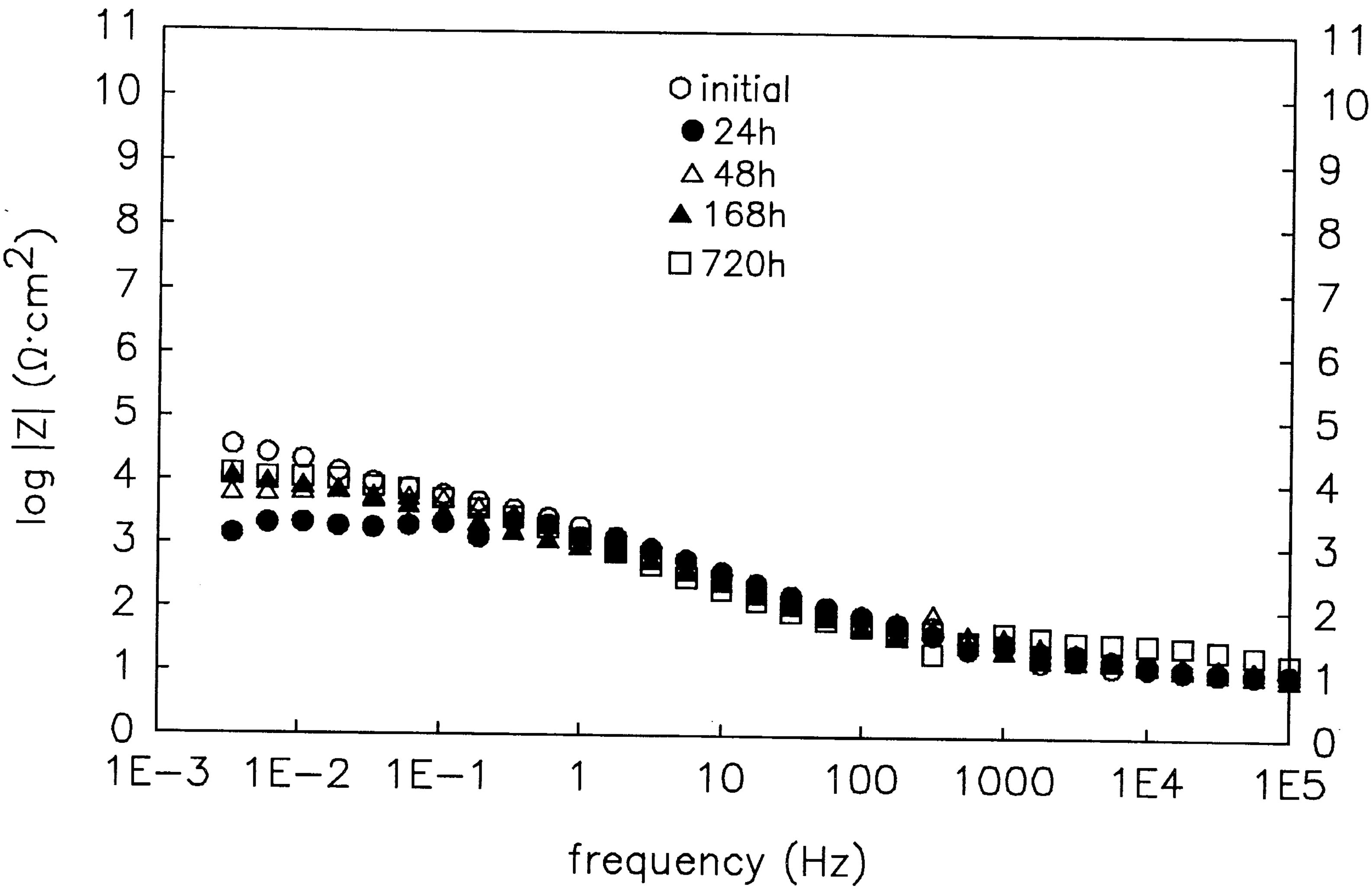

Figure 187. Impedance spectra of Epoxy 1 cured 7 days at RT with an 800 μm diameter defect on chemically cleaned Al in 0.01 M K_2SO_4 + 0.003 M KCl.

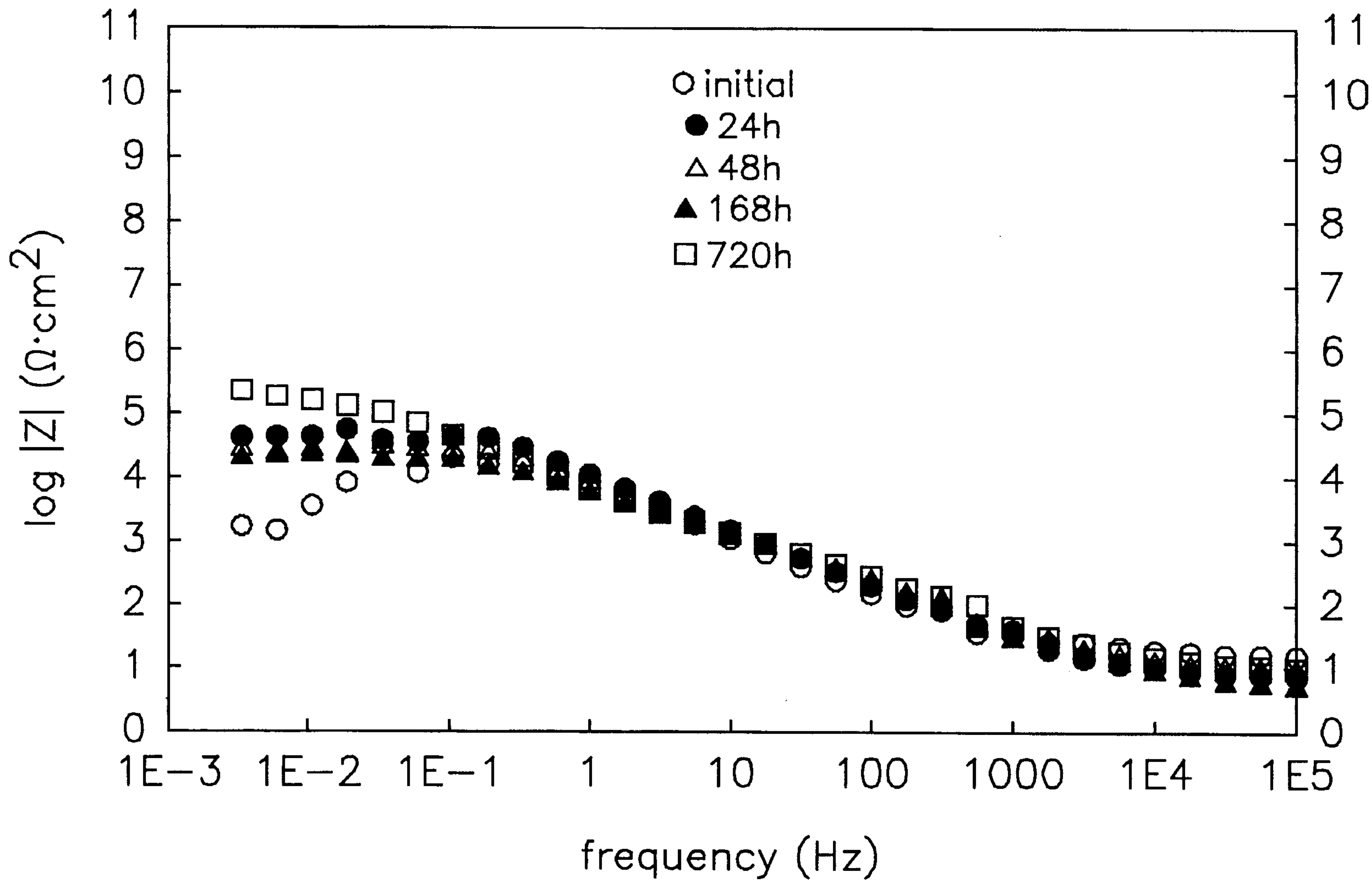

Figure 188. Impedance spectra of Epoxy 1 cured 7 days at RT with an 800 μm diameter defect on chemically cleaned Al in MPSi saturated 0.01 M K_2SO_4 + 0.003 M KCl.

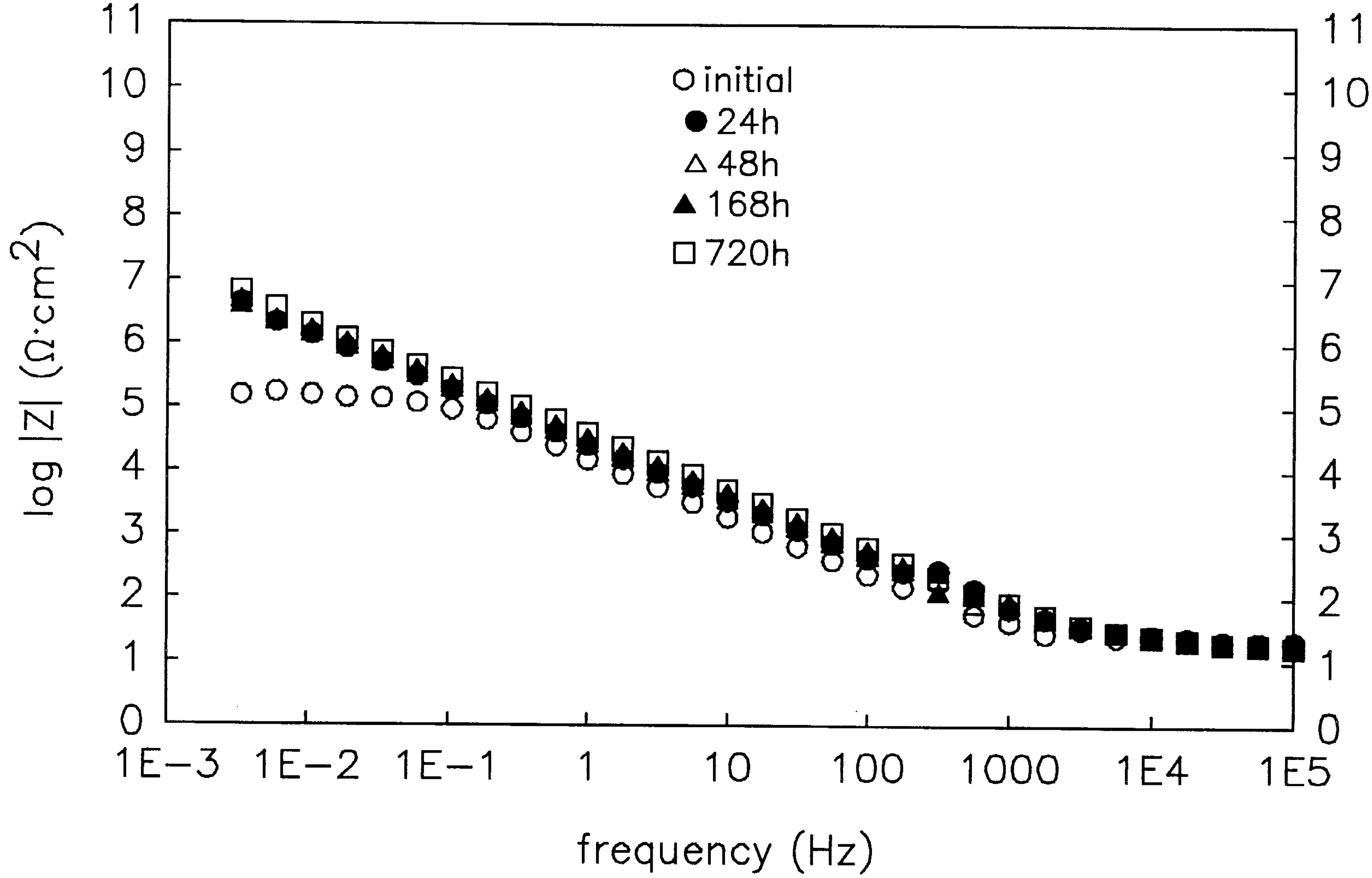

Figure 189. Impedance spectra of Epoxy 1 cured 7 days at RT with an 800 μm diameter defect on chemically cleaned Al in BaBor saturated 0.01 M K_2SO_4 + 0.003 M KCl.

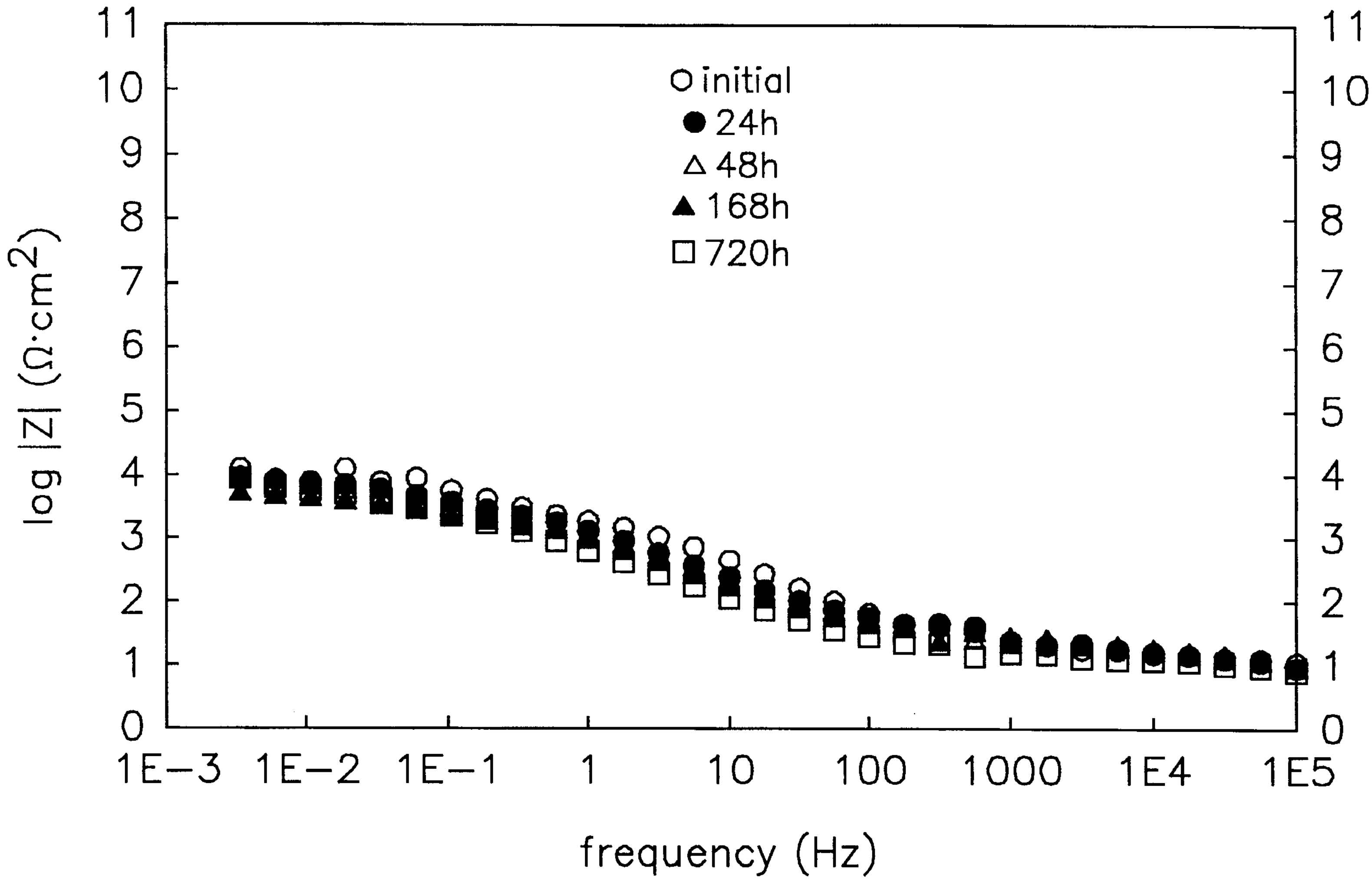

Figure 190. Impedance spectra of Epoxy 1 cured 7 days at RT with an 800 μm diameter defect on solvent cleaned Al in 0.01 M K_2SO_4 + 0.003 M KCl.

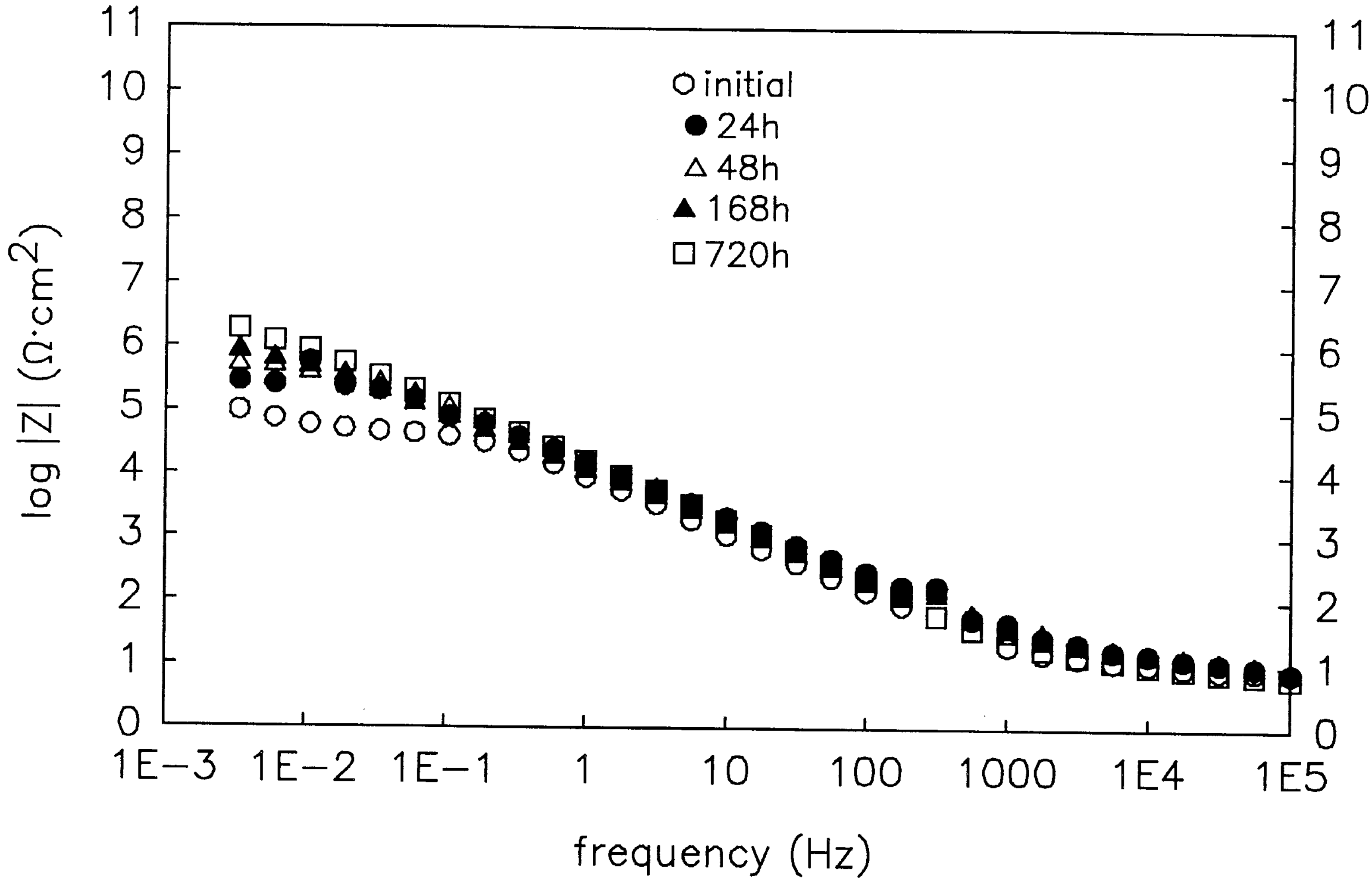

Figure 191. Impedance spectra of Epoxy 1 cured 7 days at RT with an 800 μm diameter defect on solvent cleaned Al in MPSi saturated 0.01 M K_2SO_4 + 0.003 M KCl.

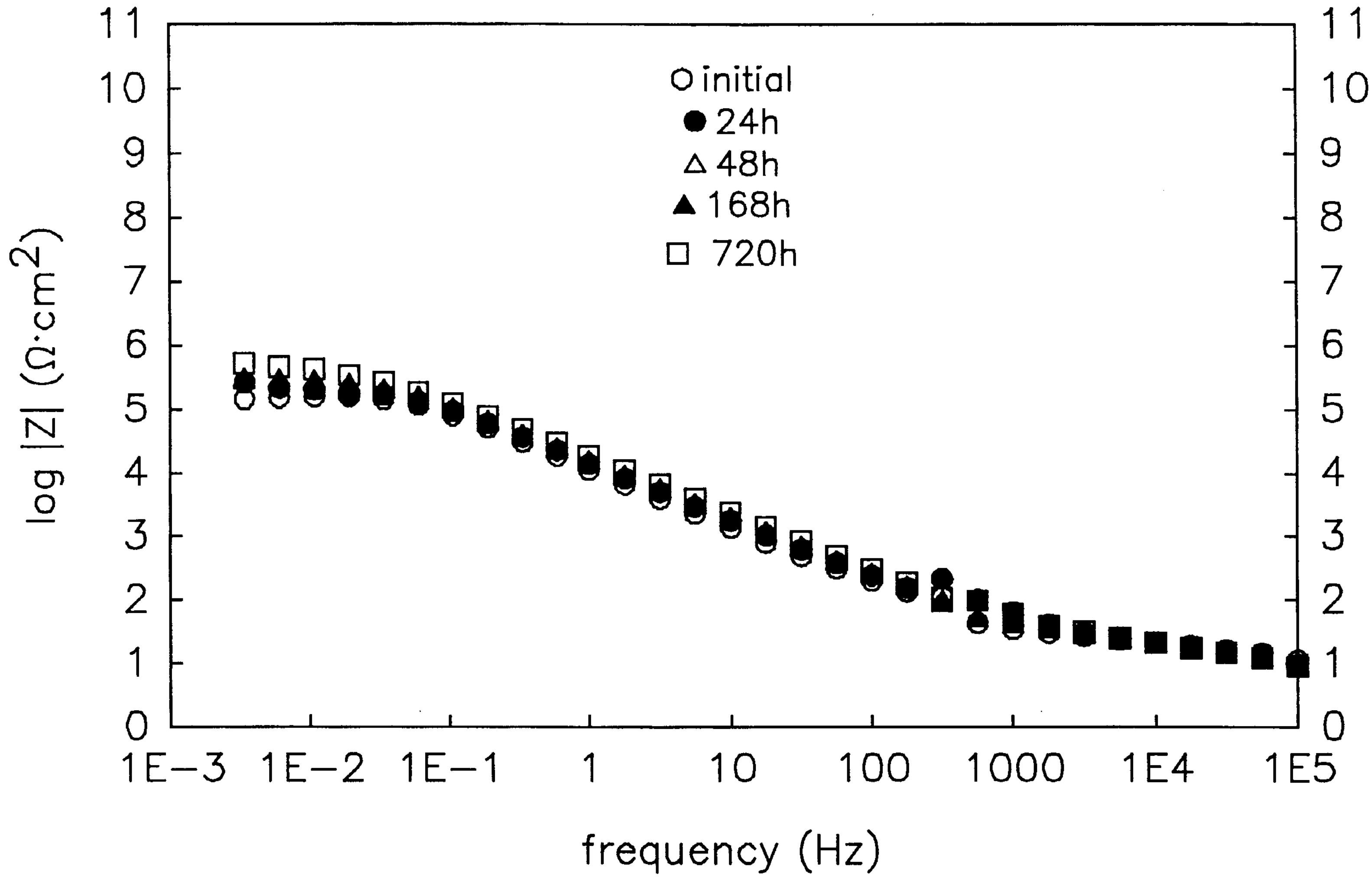

Figure 192. Impedance spectra of Epoxy 1 cured 7 days at RT with an 800 µm diameter defect on solvent cleaned Al in BaBor saturated 0.01 M K_2SO_4 + 0.003 M KCl.

ZDOC/95FINAL/APP

ZERO DISCHARGE ORGANIC COATINGS
Powder Paint - UV Curable Paint - E-Coat

APPENDIX H

Polarization Curves for the Inhibitor Characterization and Analysis

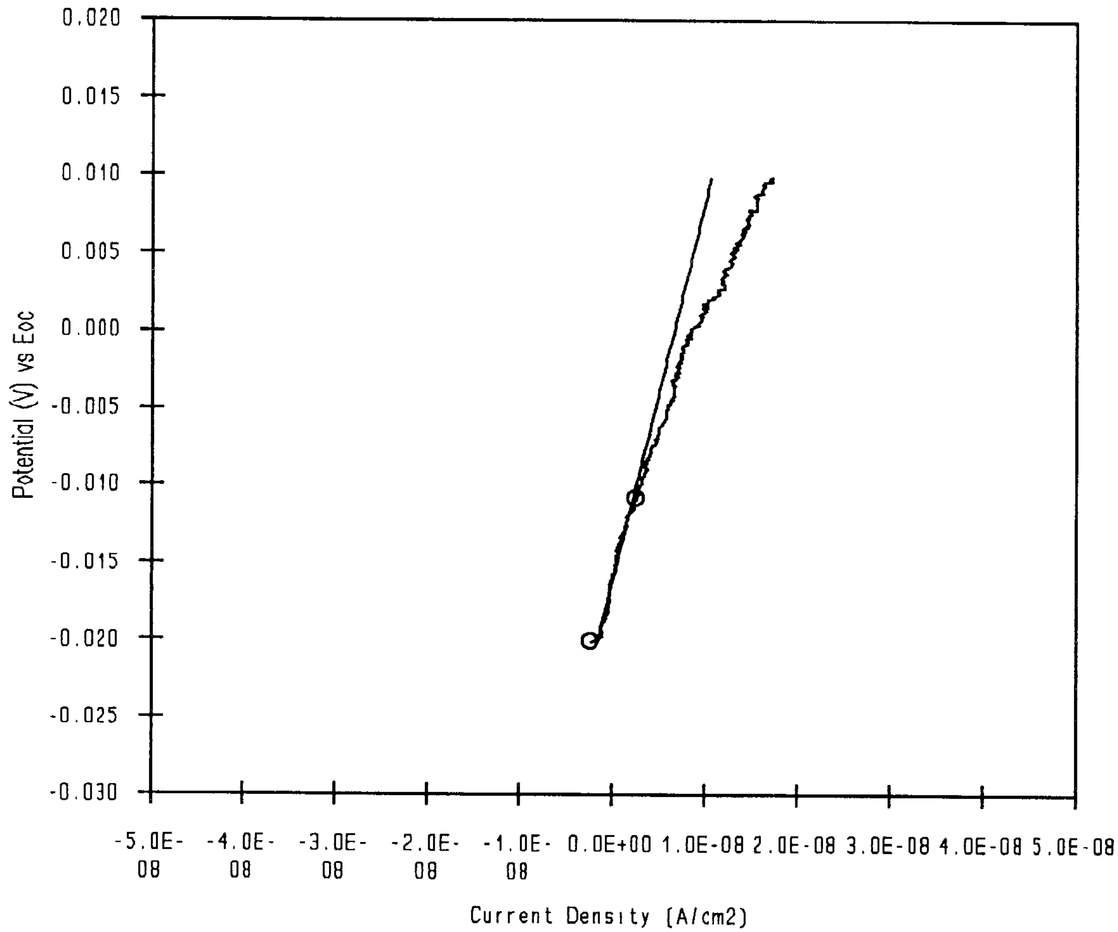

Figure 193. Initial polarization resistance curve of Epoxy 3 cured 2 h at 100°C on CCC Al with in 0.01 M K_2SO_4.

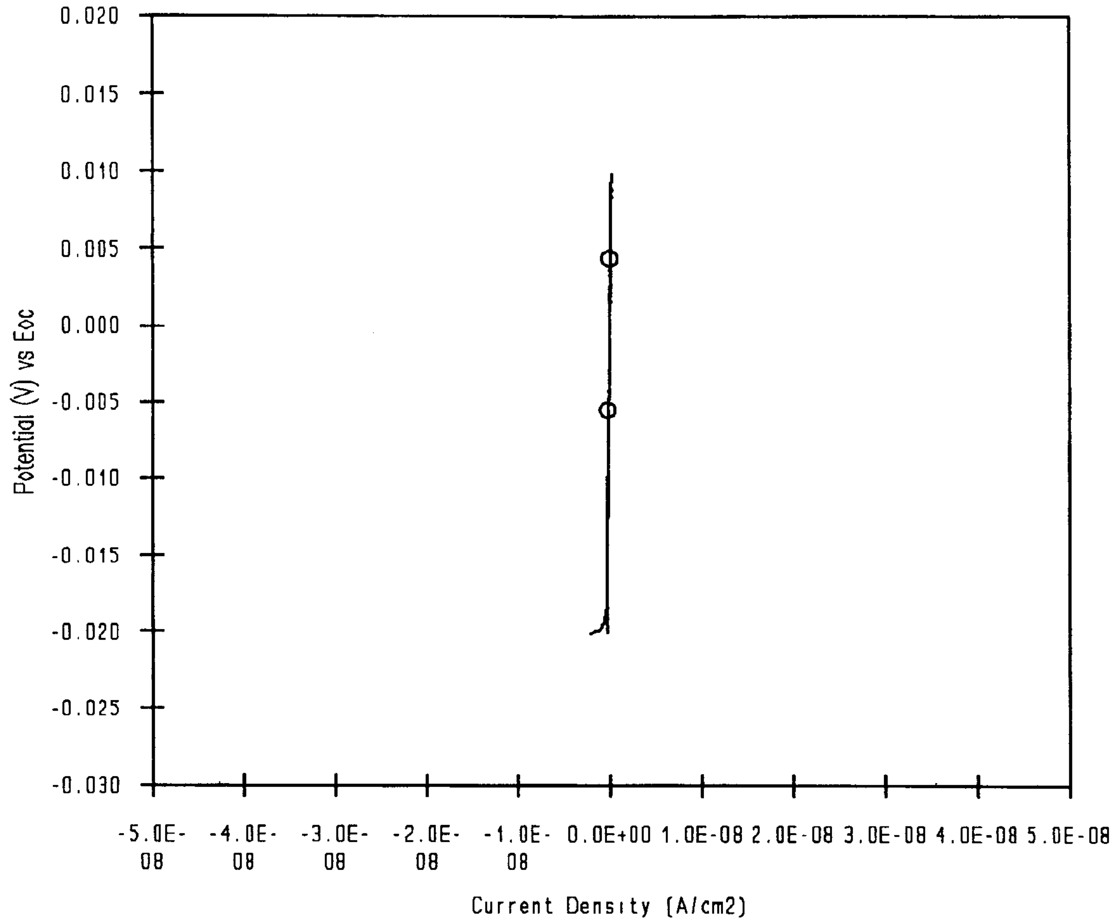

Figure 194. 24 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C on CCC Al in 0.01 M K_2SO_4.

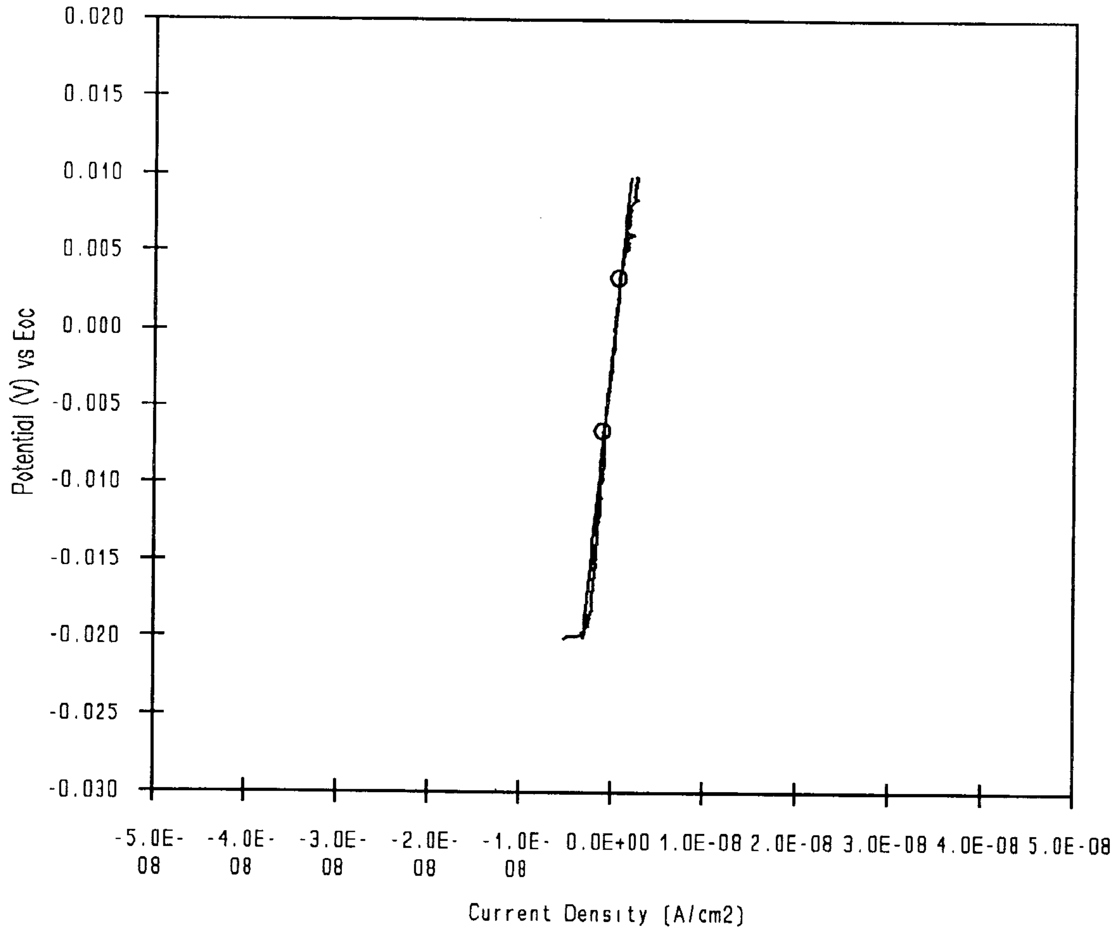

Figure 195. 48 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C on CCC Al in 0.01 M K_2SO_4.

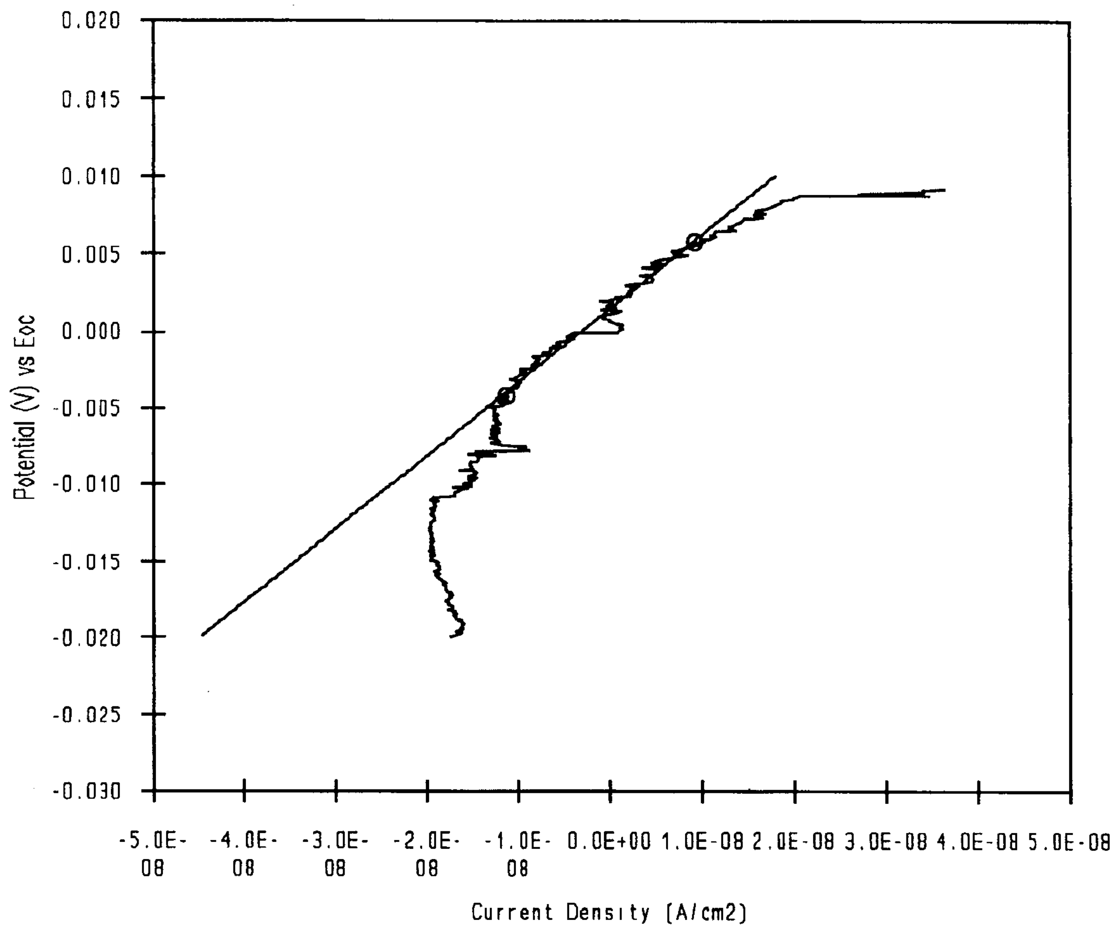

Figure 196. Initial polarization curve of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al in 0.01 M K_2SO_4.

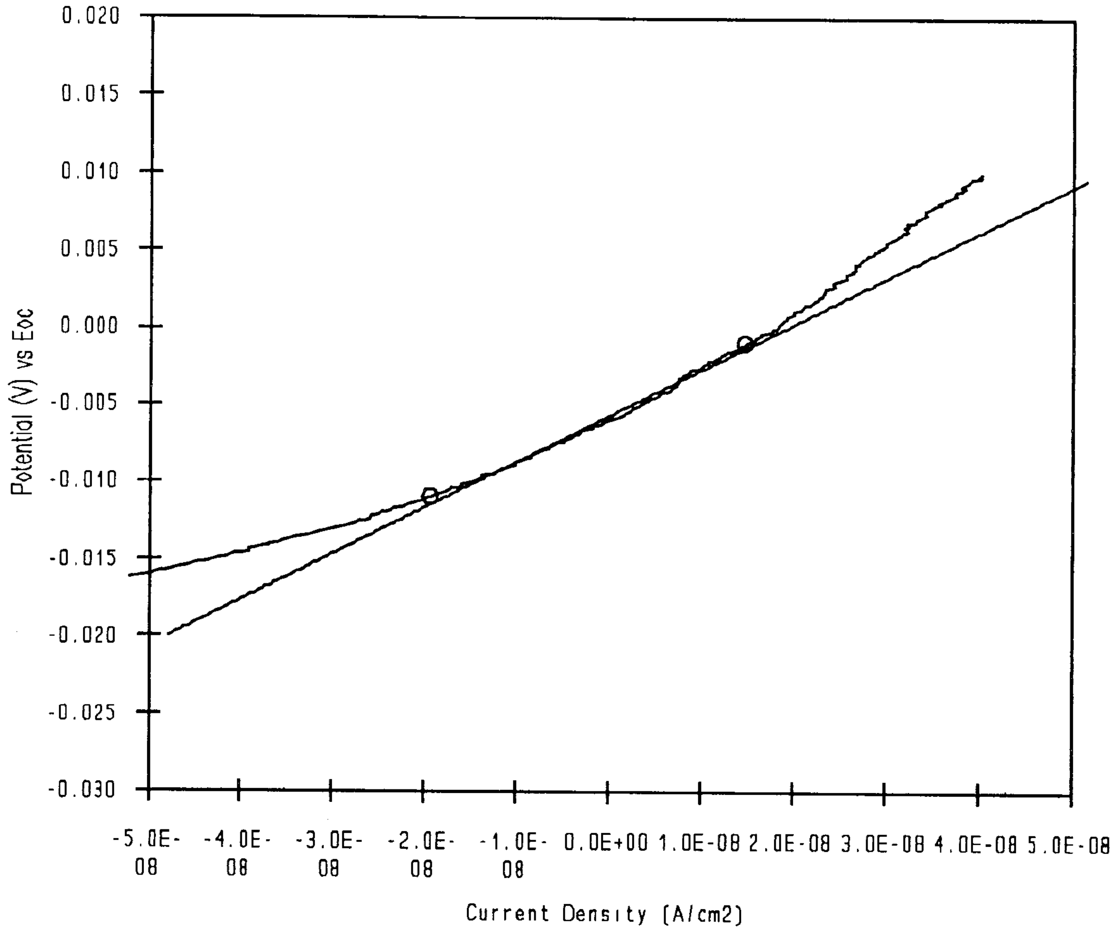

Figure 197. 24 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al in 0.01 M K_2SO_4.

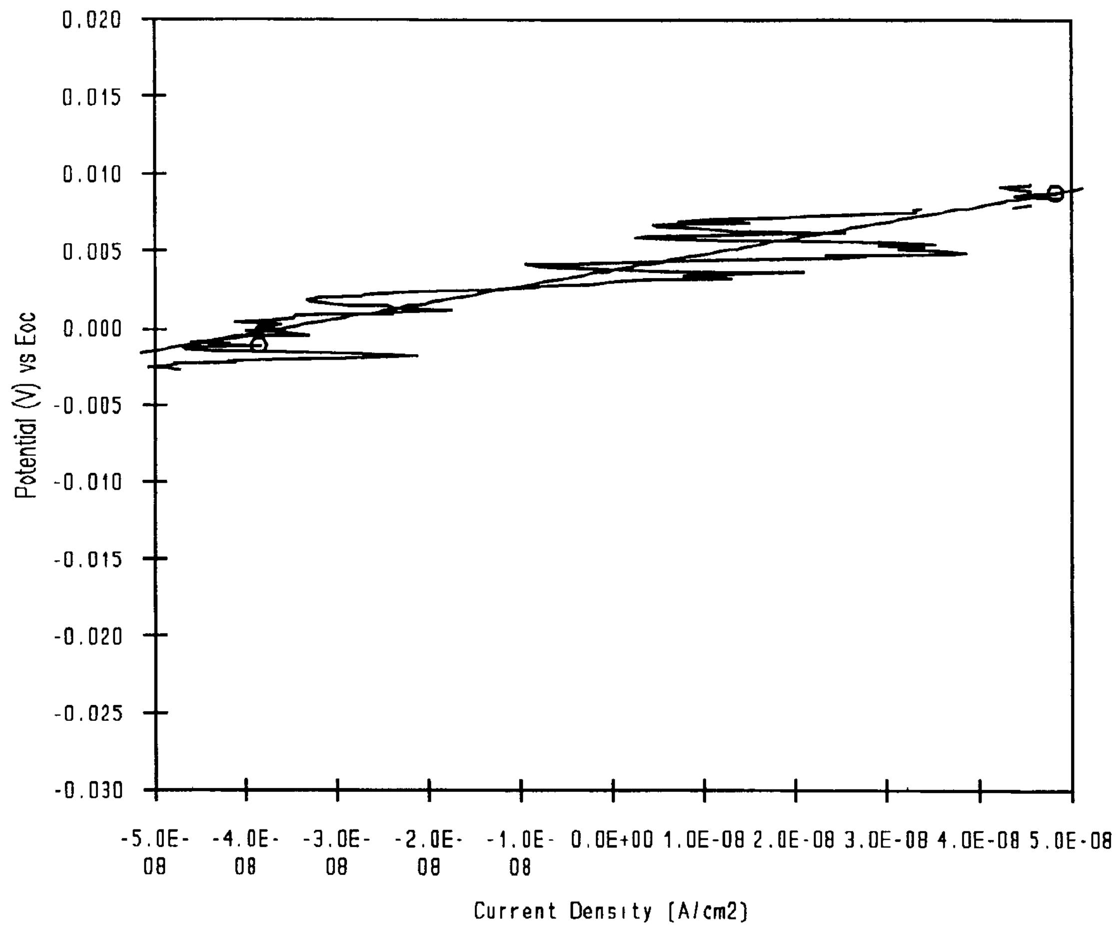

Figure 198. 48 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C on chemically cleaned Al in 0.01 M K_2SO_4.

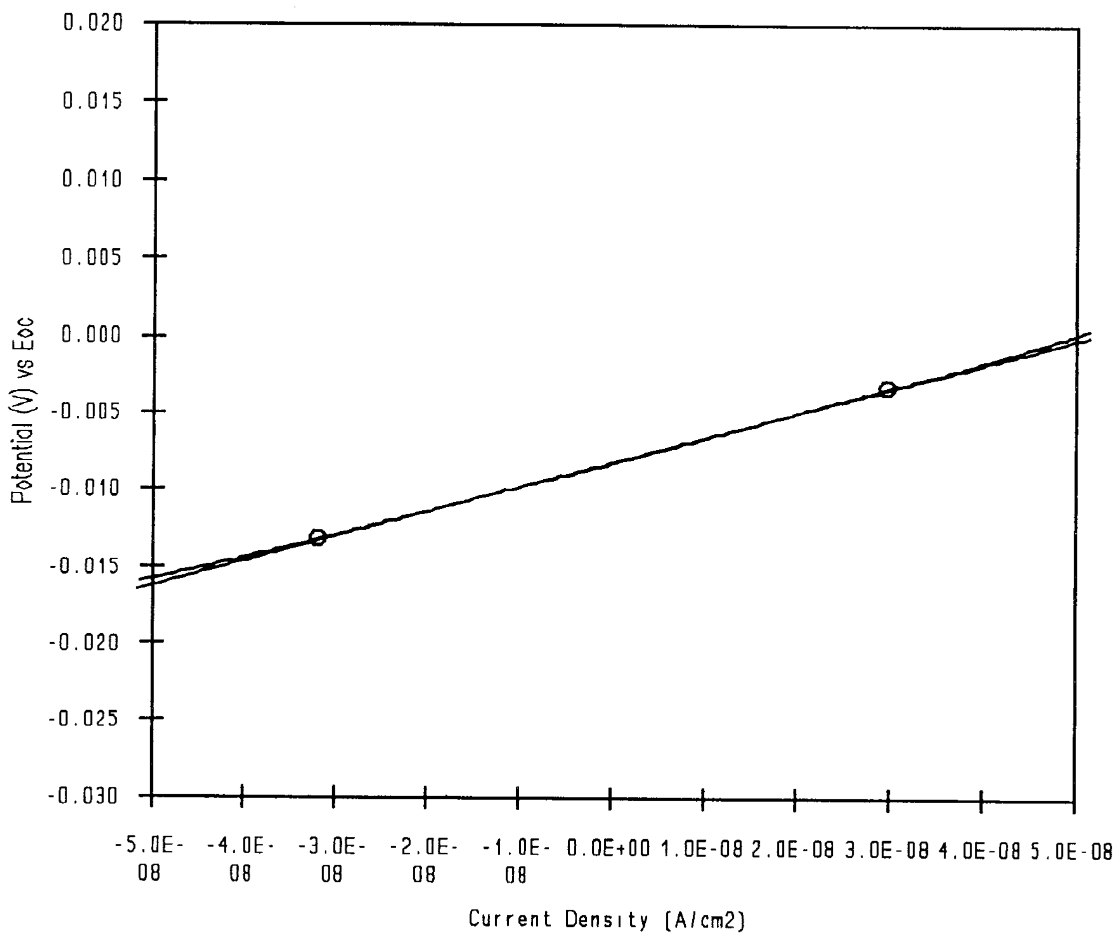

Figure 199. Initial polarization curve of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al in 0.01 M K_2SO_4.

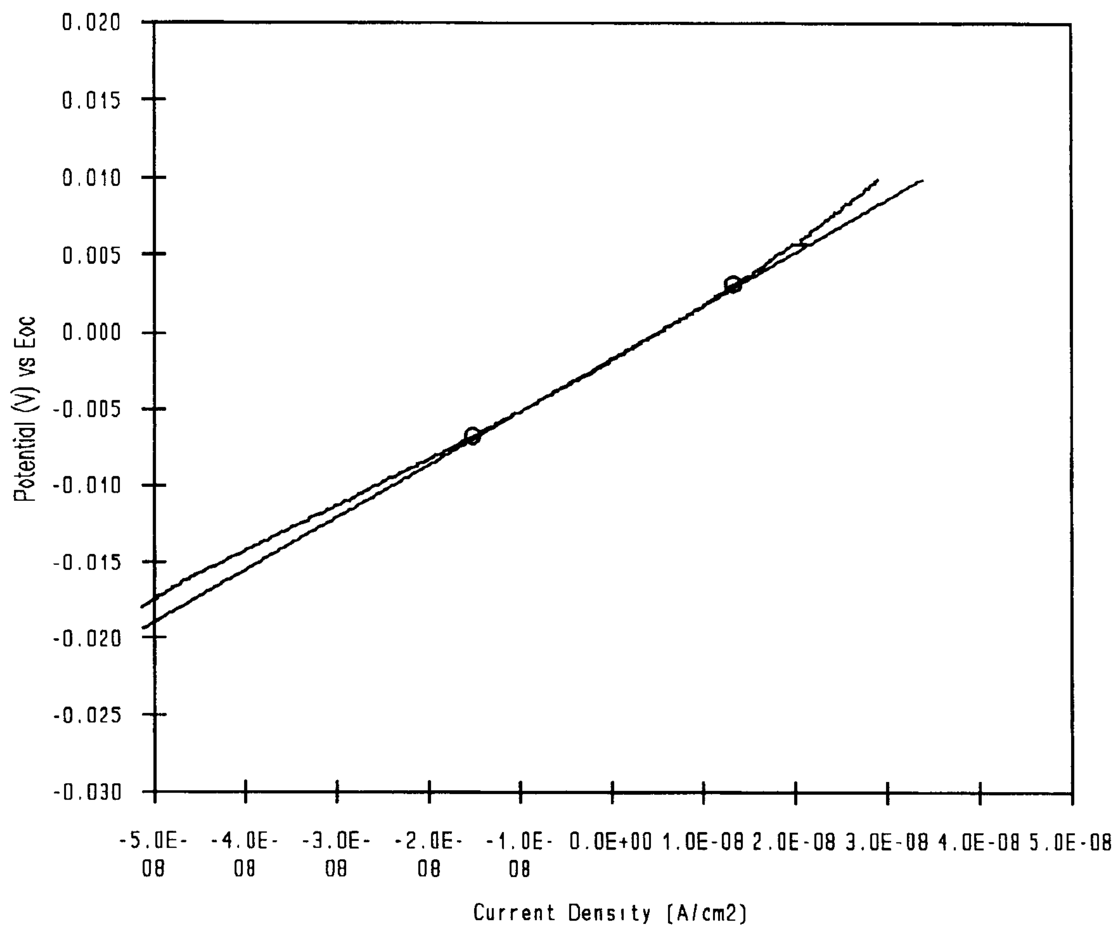

Figure 200. 24 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al in 0.01 M K_2SO_4.

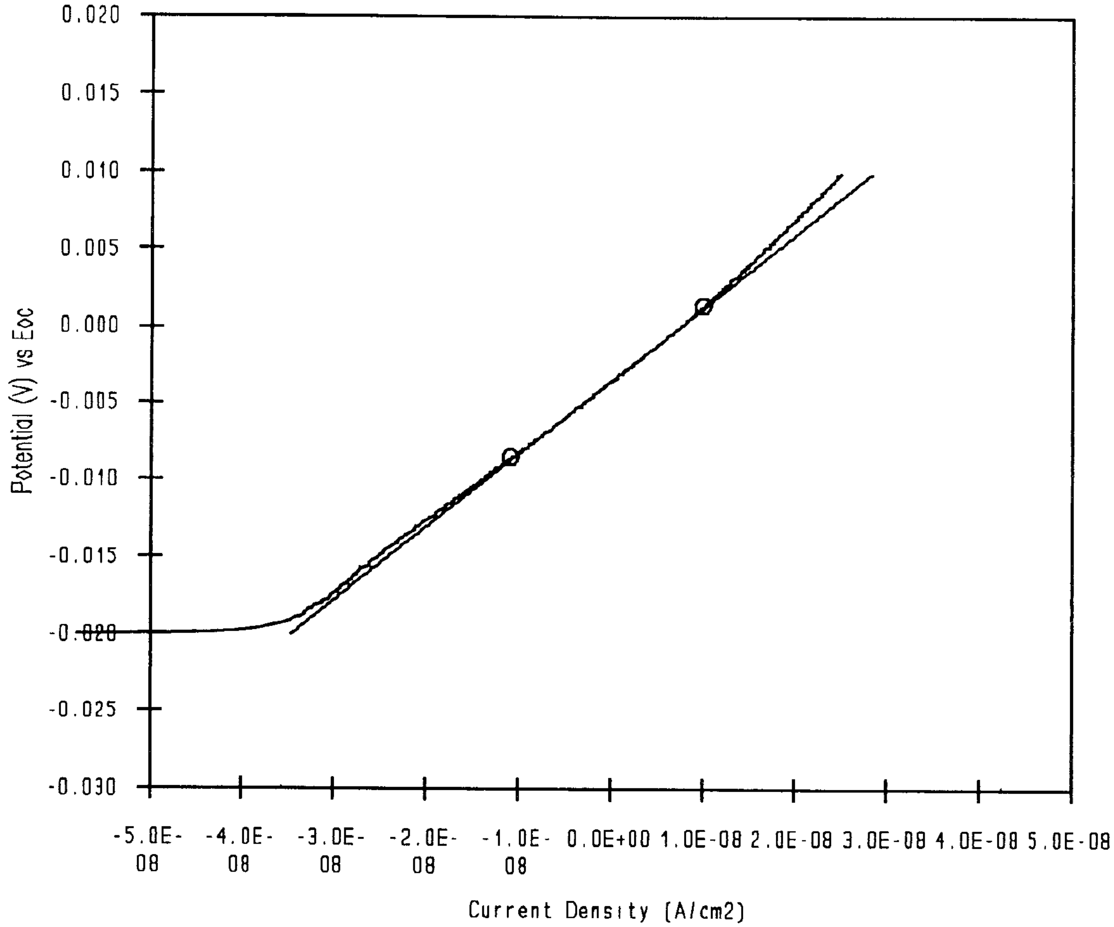

Figure 201. 48 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C on solvent cleaned Al in 0.01 M K_2SO_4.

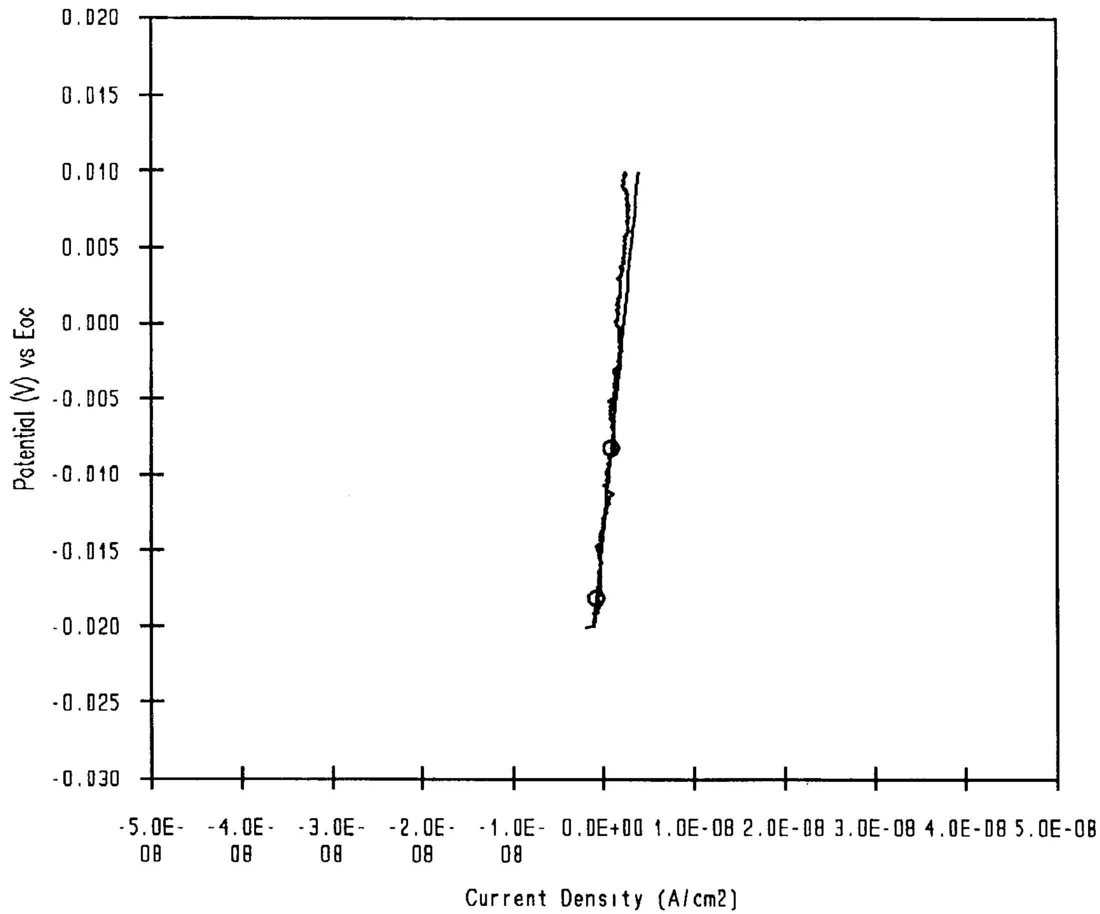

Figure 202. Initial polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% MPSi in the coating on CCC Al in 0.01 M K_2SO_4.

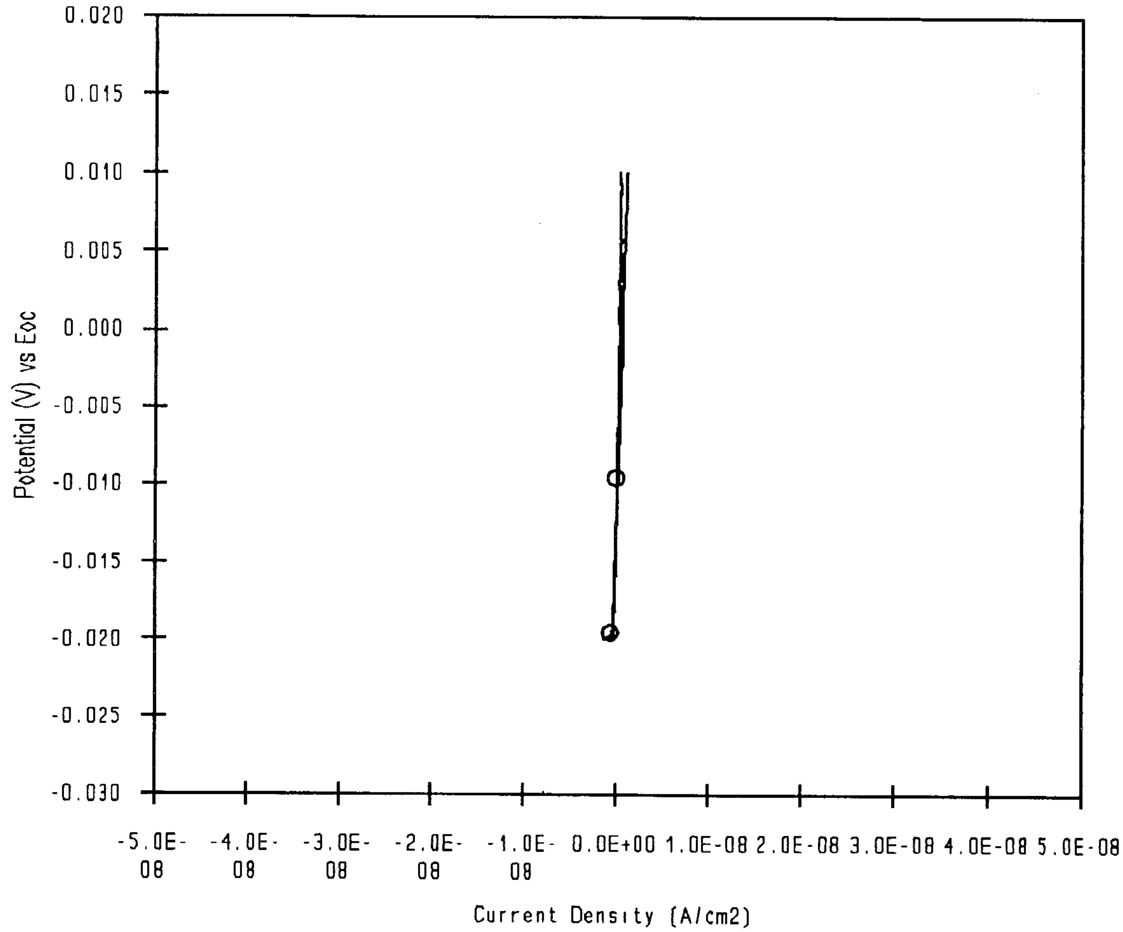

Figure 203. 24 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% MPSi in the coating on CCC Al in 0.01 M K_2SO_4.

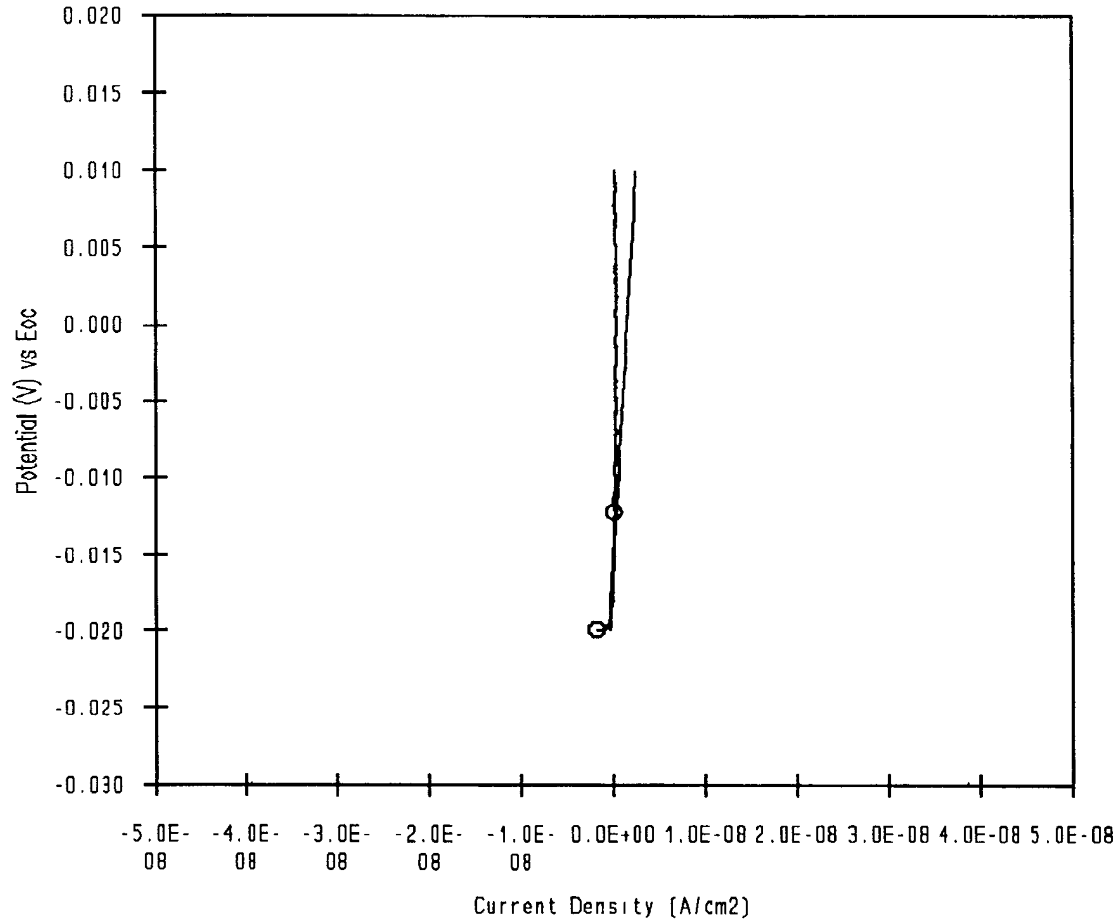

Figure 204. 48 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% MPSi in the coating on CC Al in 0.01 M K_2SO_4.

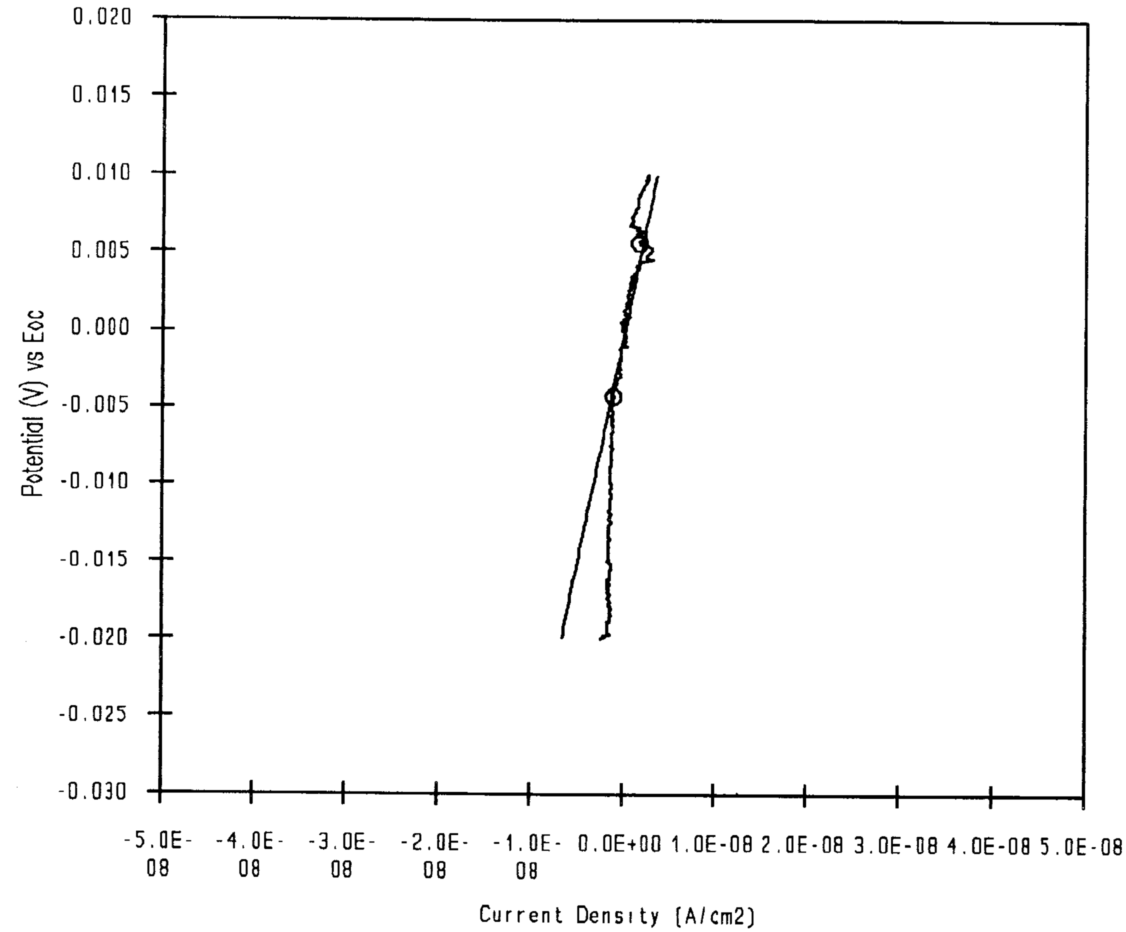

Figure 205. Initial polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% MPSi in the coating on chemically cleaned Al in 0.01 M K_2SO_4.

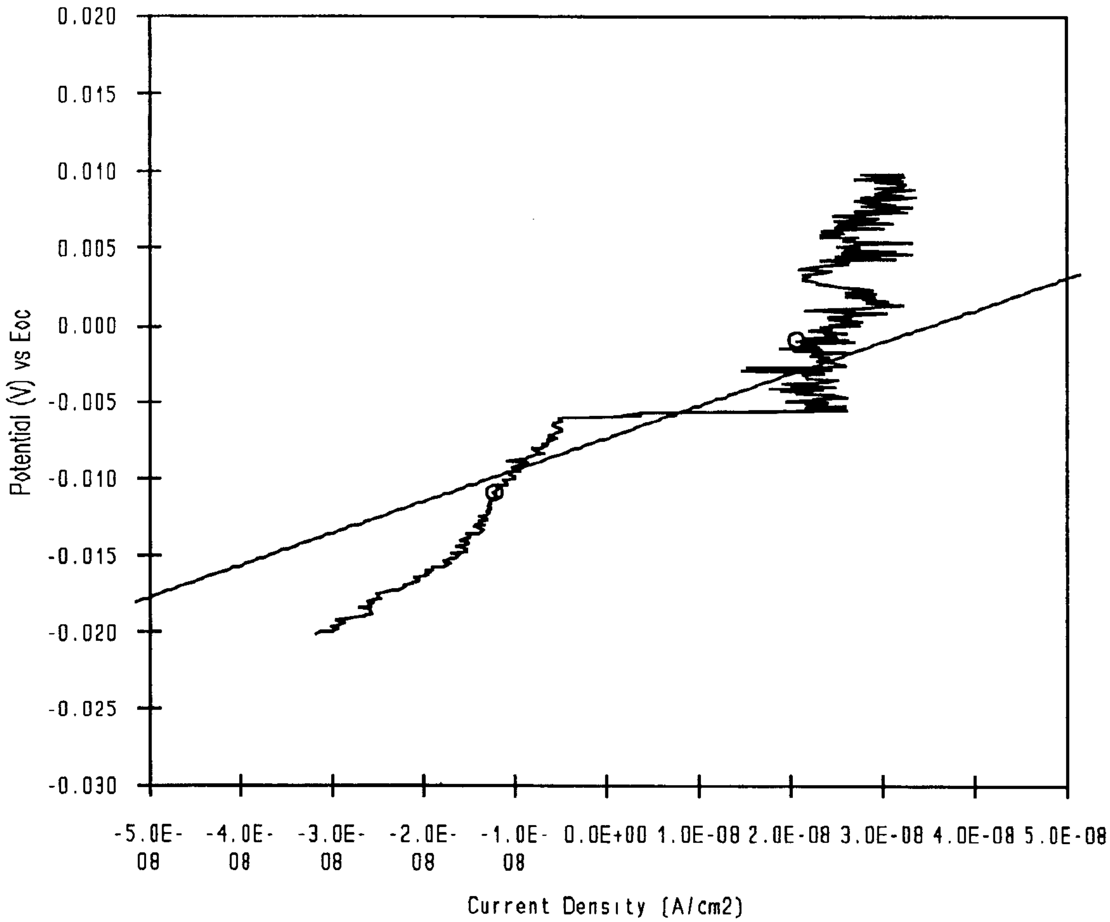

Figure 206. 24 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% MPSi in the coating on chemically cleaned Al in 0.01 M K_2SO_4.

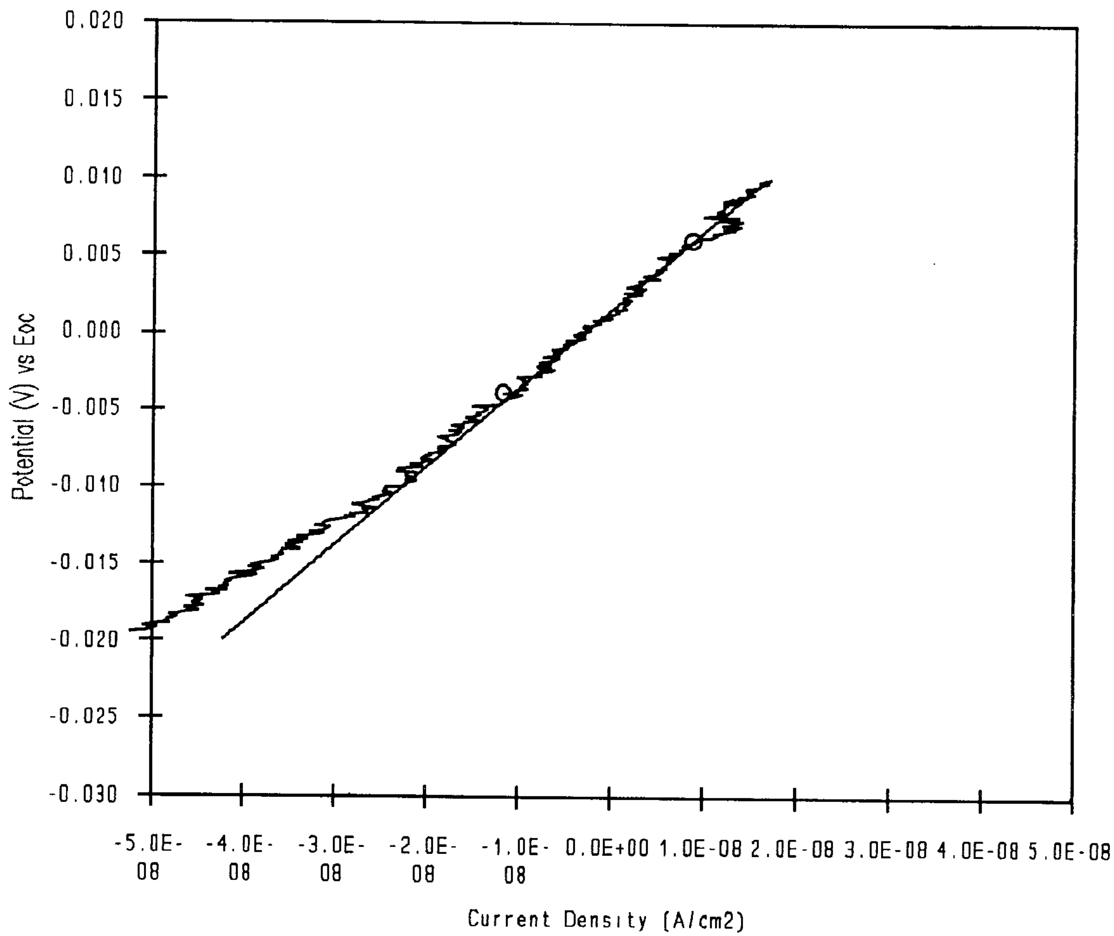

Figure 207. 48 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% MPSi in the coating on chemically cleaned Al in 0.01 M K_2SO_4.

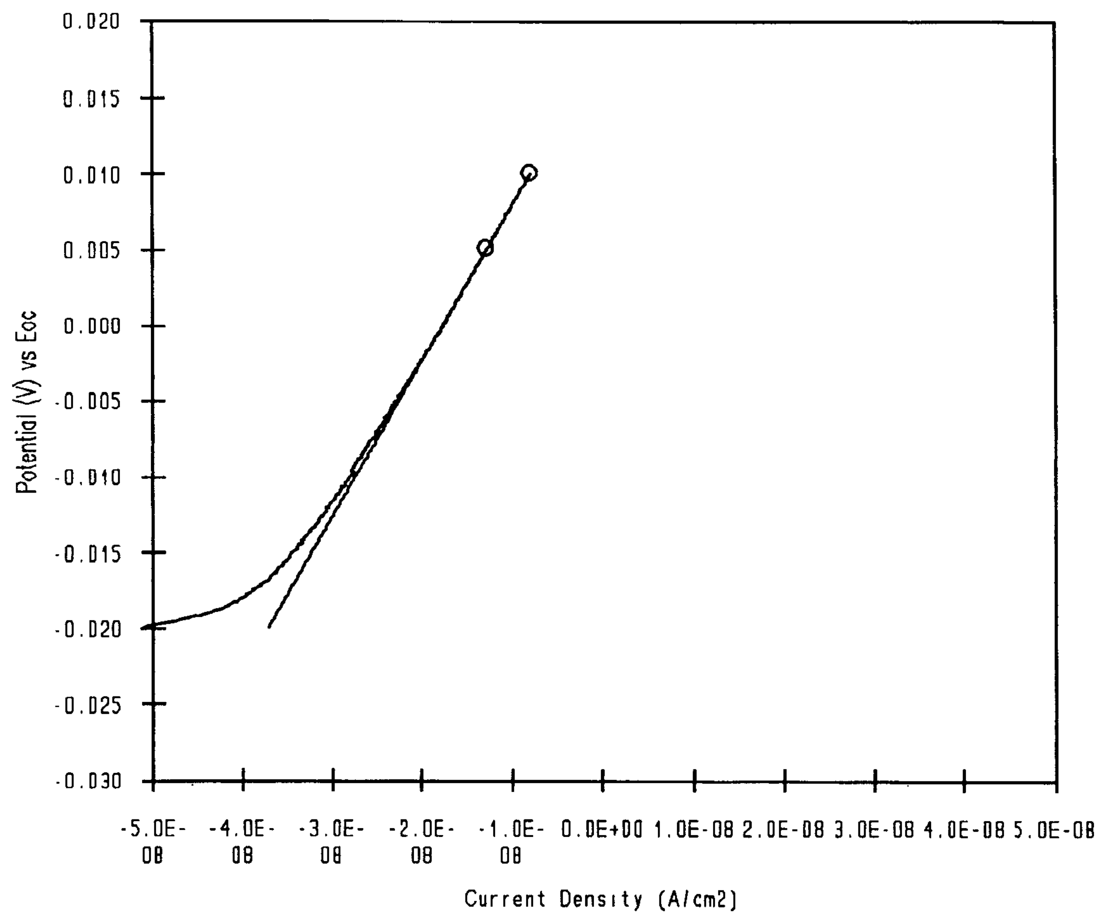

Figure 208. Initial polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% MPSi in the coating on solvent cleaned Al in 0.01 M K_2SO_4.

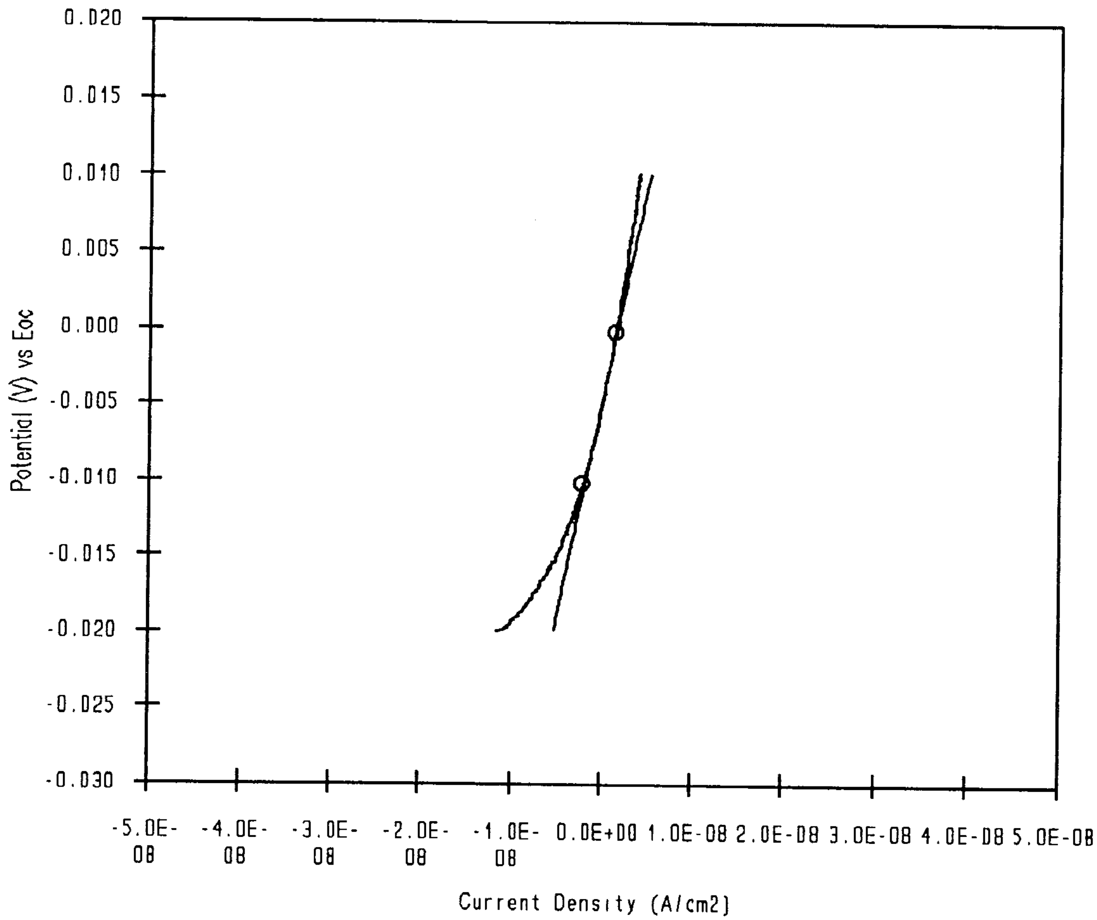

Figure 209. 24 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% MPSi in the coating on solvent cleaned Al in 0.01 M K_2SO_4.

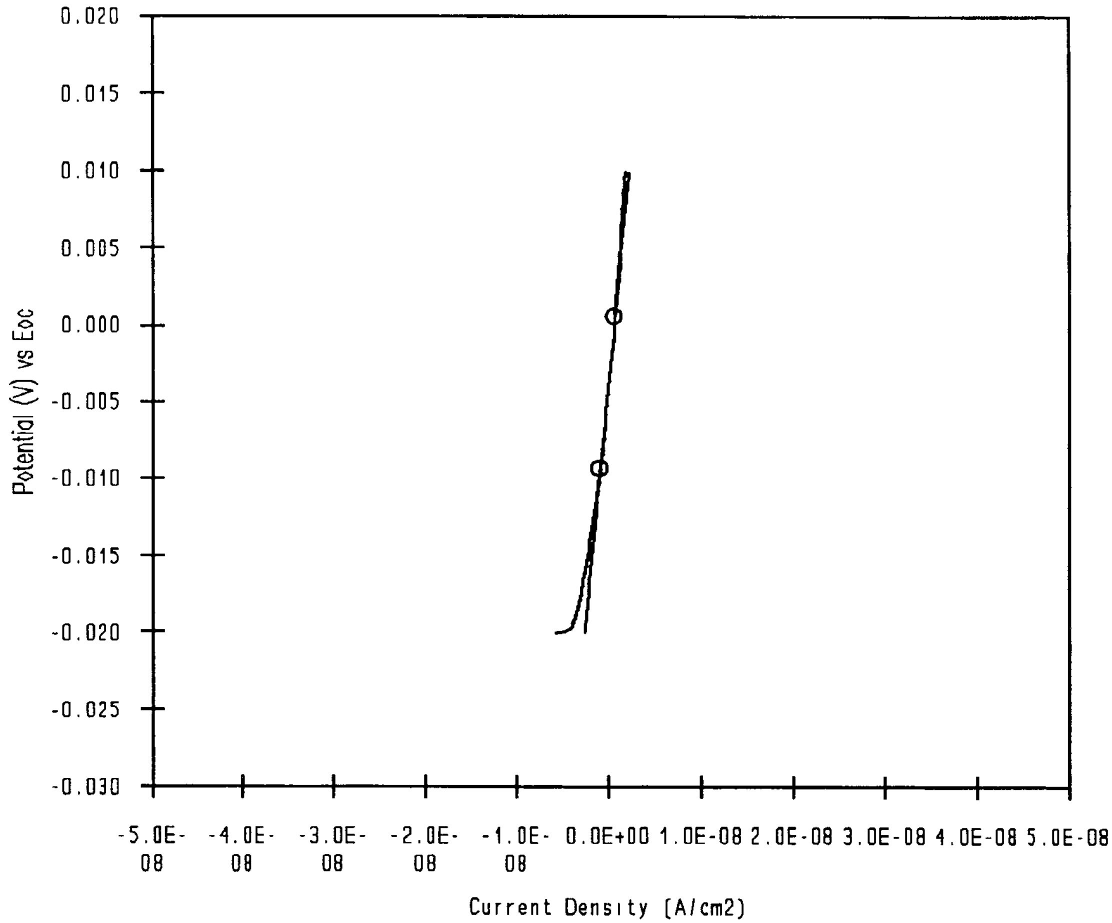

Figure 210. 48 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% MPSi in the coating on solvent cleaned Al in 0.01 M K_2SO_4.

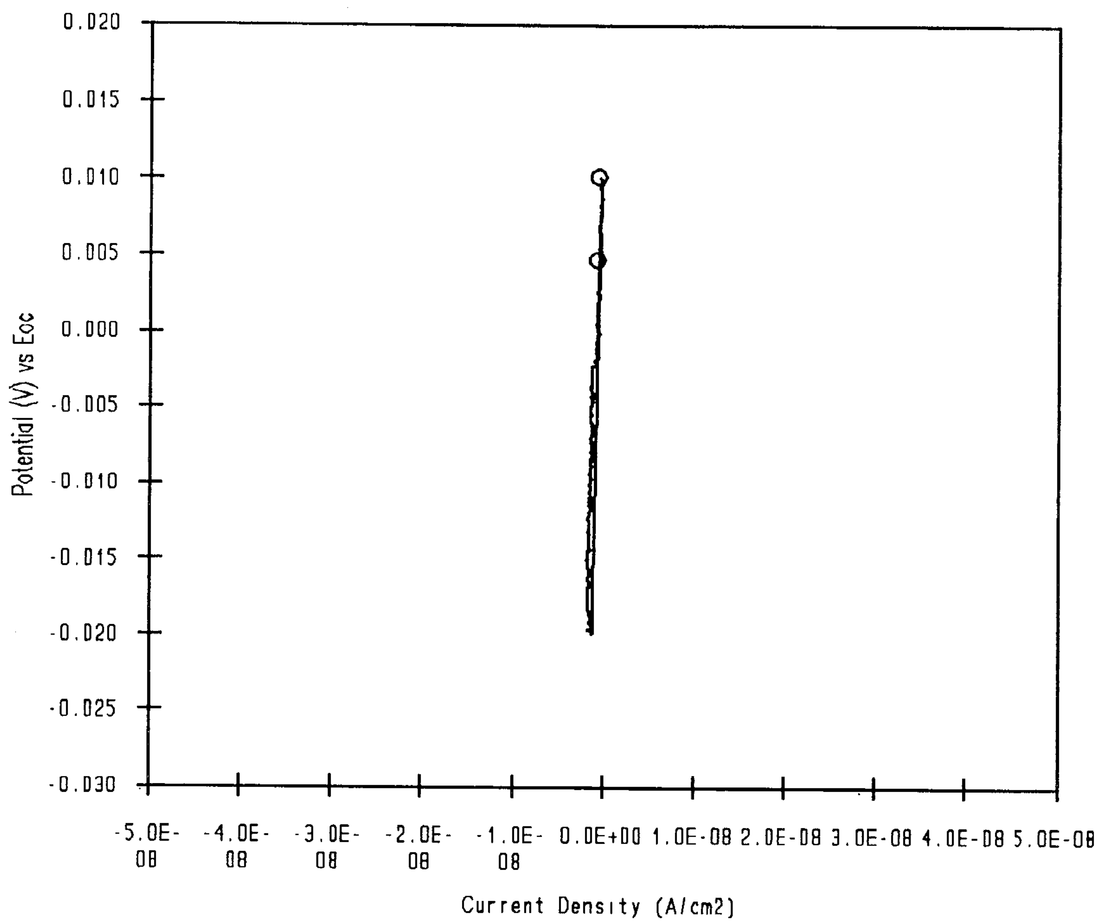

Figure 211. Initial polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% BaBor in the coating on CCC Al in 0.01 M K_2SO_4.

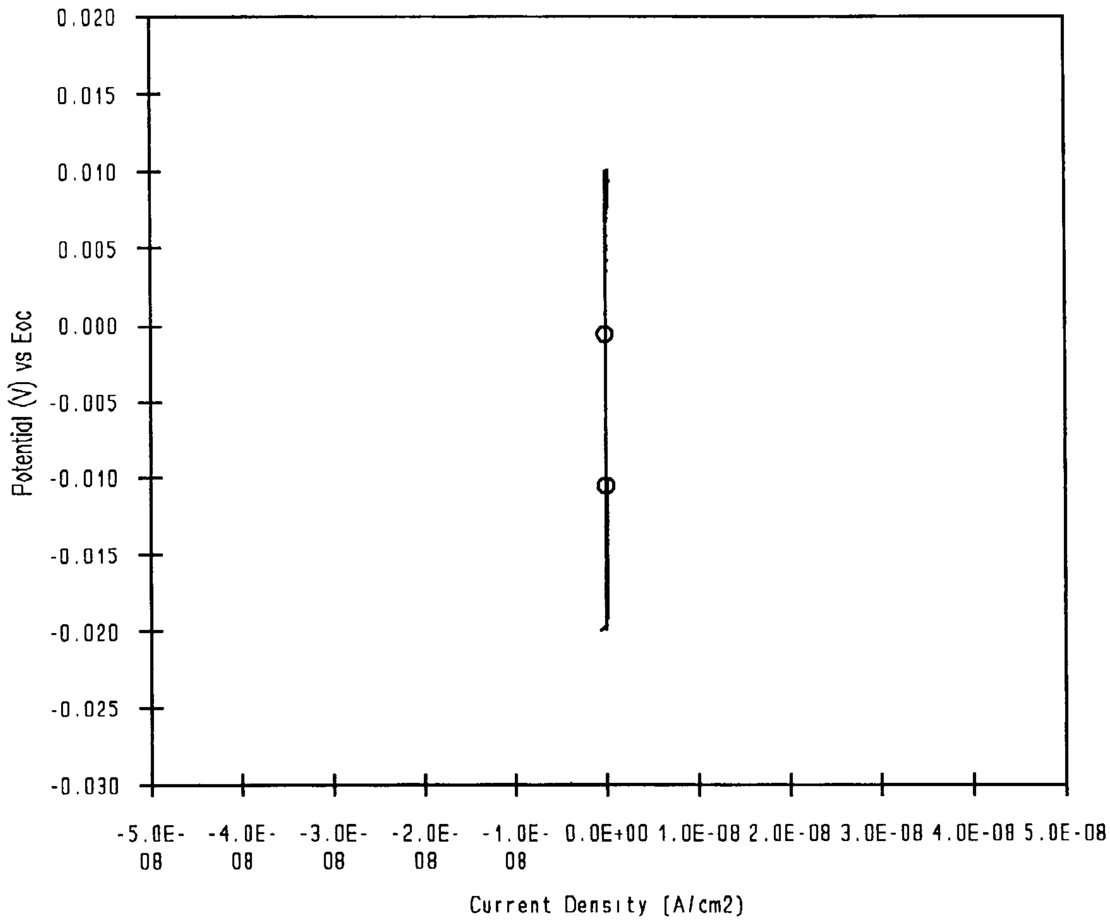

Figure 212. 24 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% BaBor in the coating on CCC Al in 0.01 M K_2SO_4.

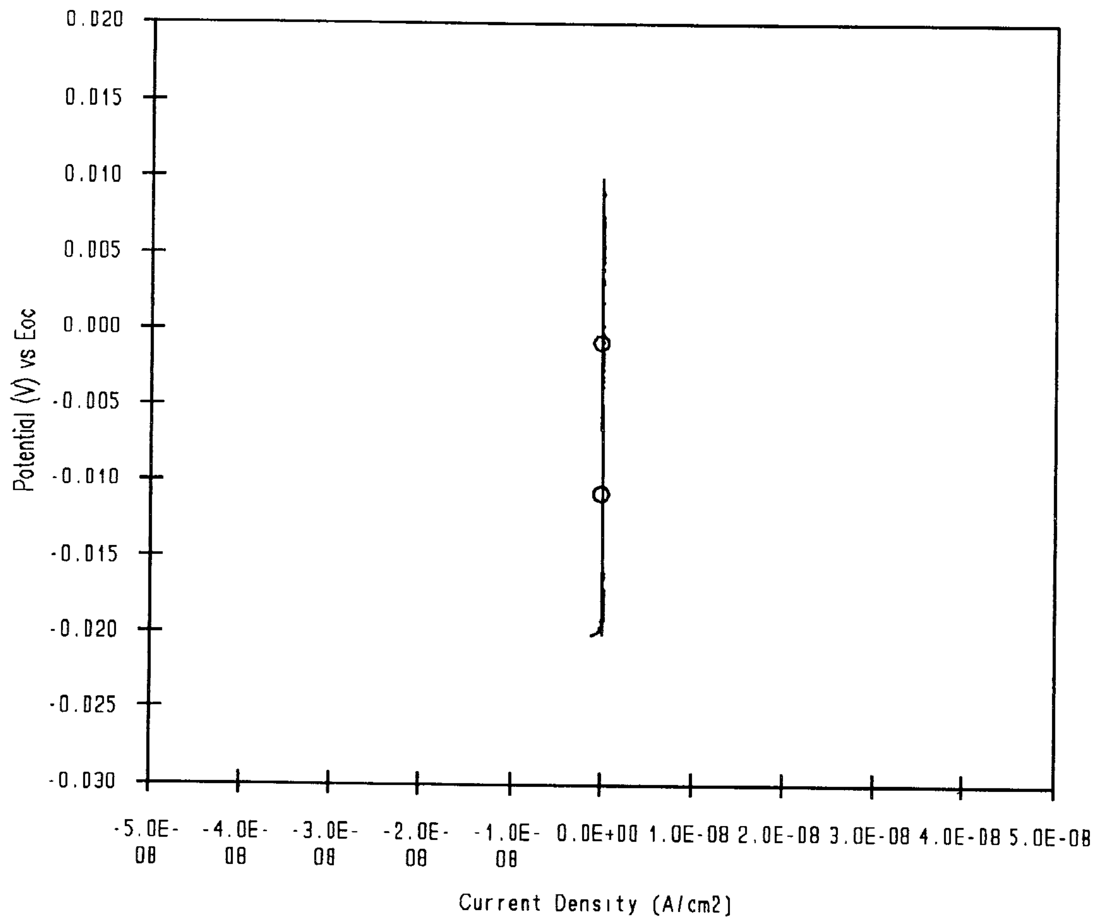

Figure 213. 48 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% BaBor in the coating on CCC Al in 0.01 M K_2SO_4.

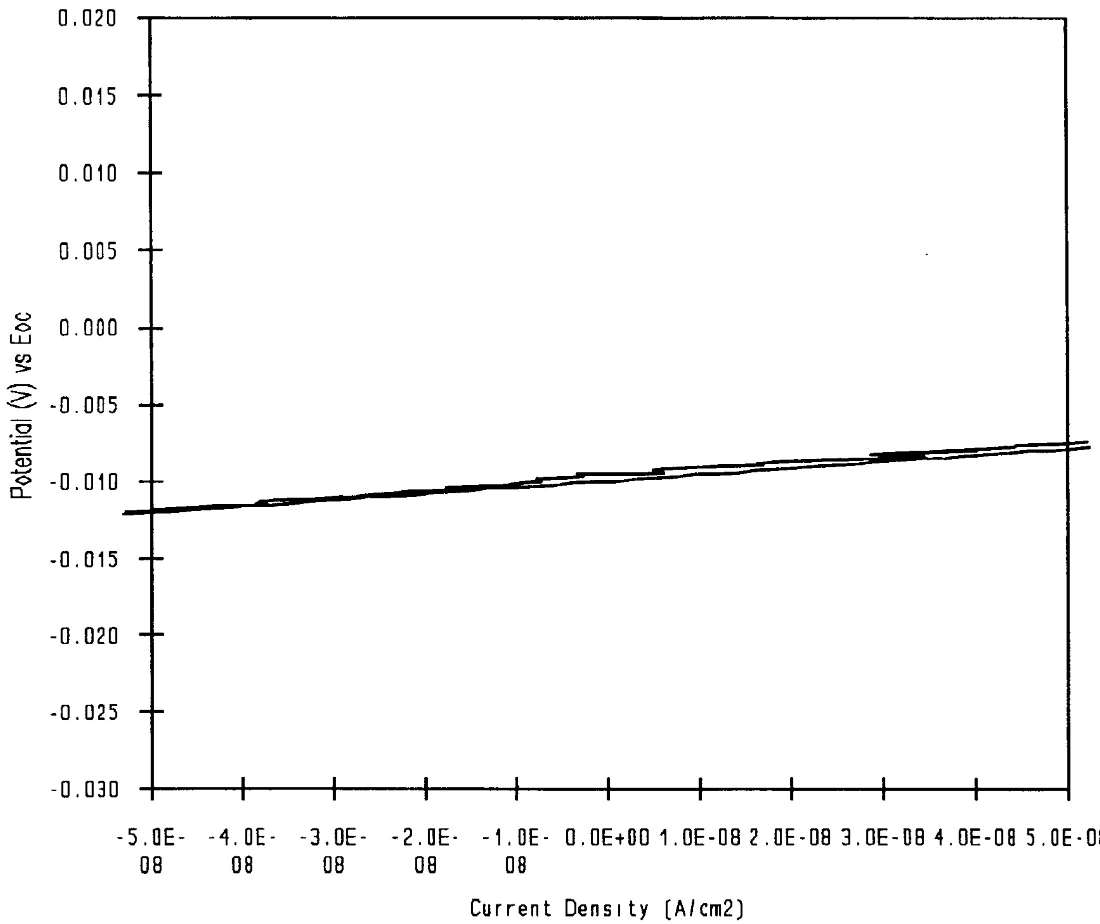

Figure 214. Initial polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% BaBor in the coating on chemically cleaned Al in 0.01 M K_2SO_4.

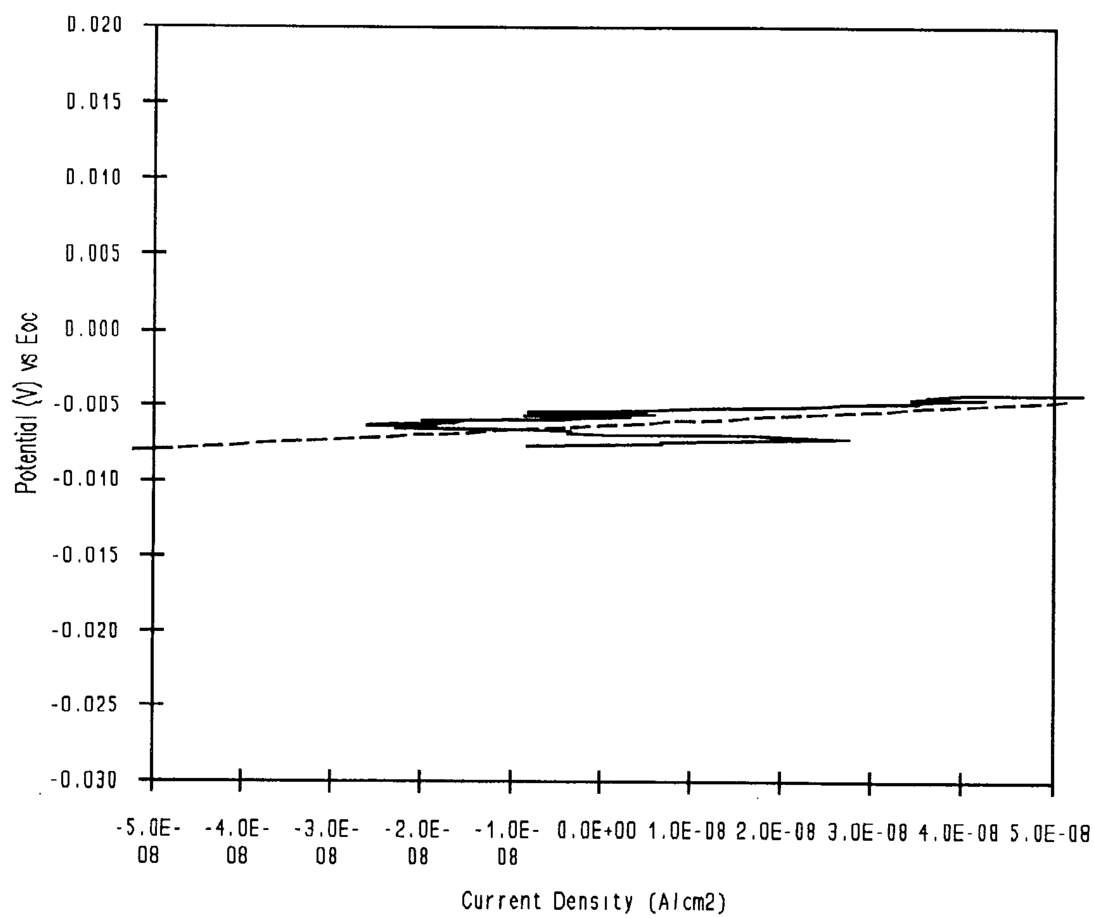

Figure 215. 24 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% BaBor in the coating on chemically cleaned Al in 0.01 M K_2SO_4.

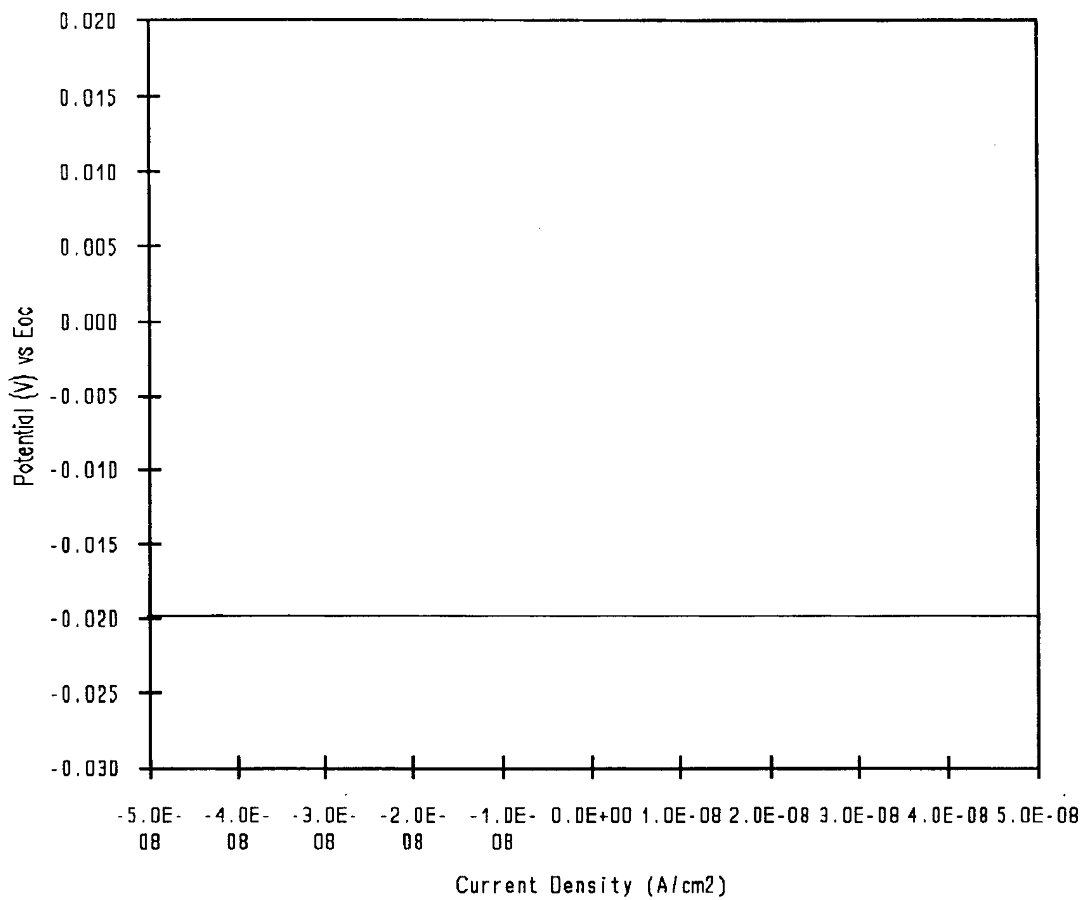

Figure 216. 48 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% BaBor in the coating on chemically cleaned Al in 0.01 M K_2SO_4.

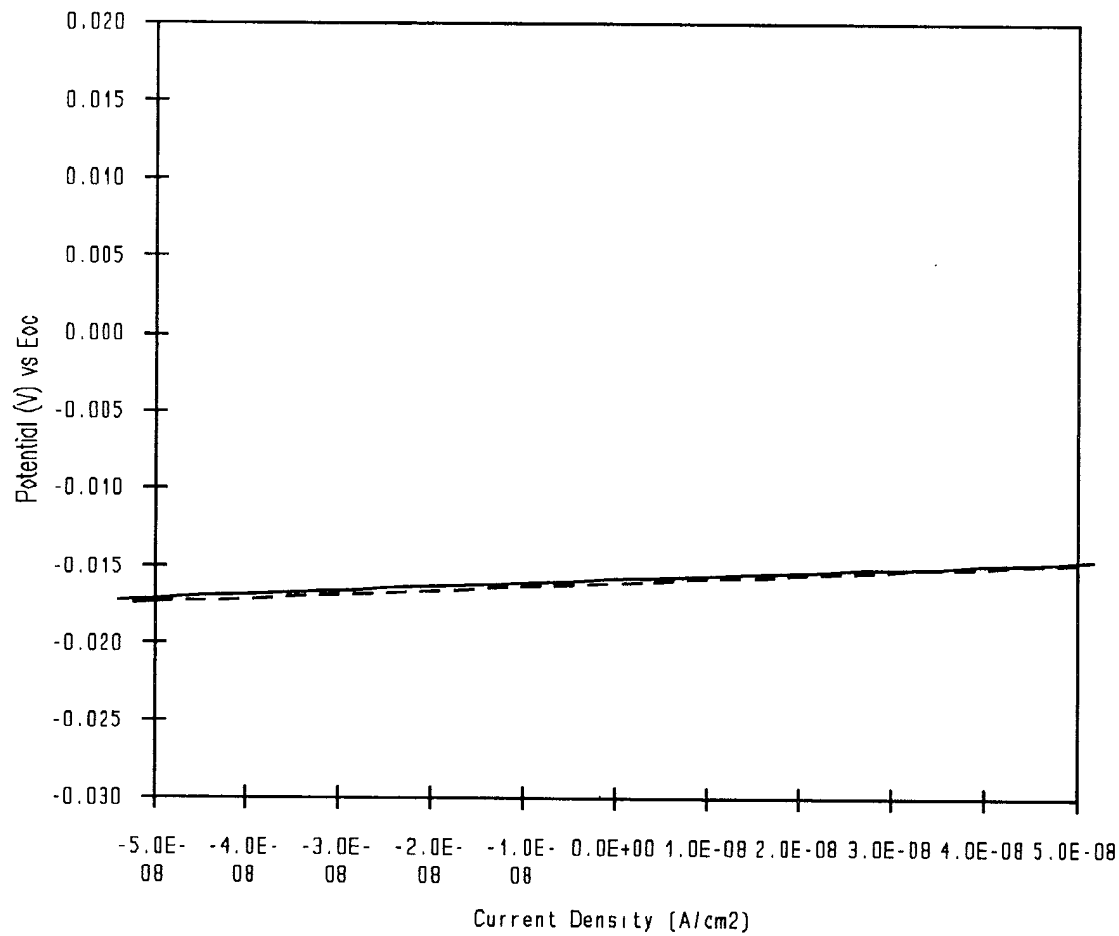

Figure 217. Initial polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% BaBor in the coating on solvent cleaned Al in 0.01 M K_2SO_4.

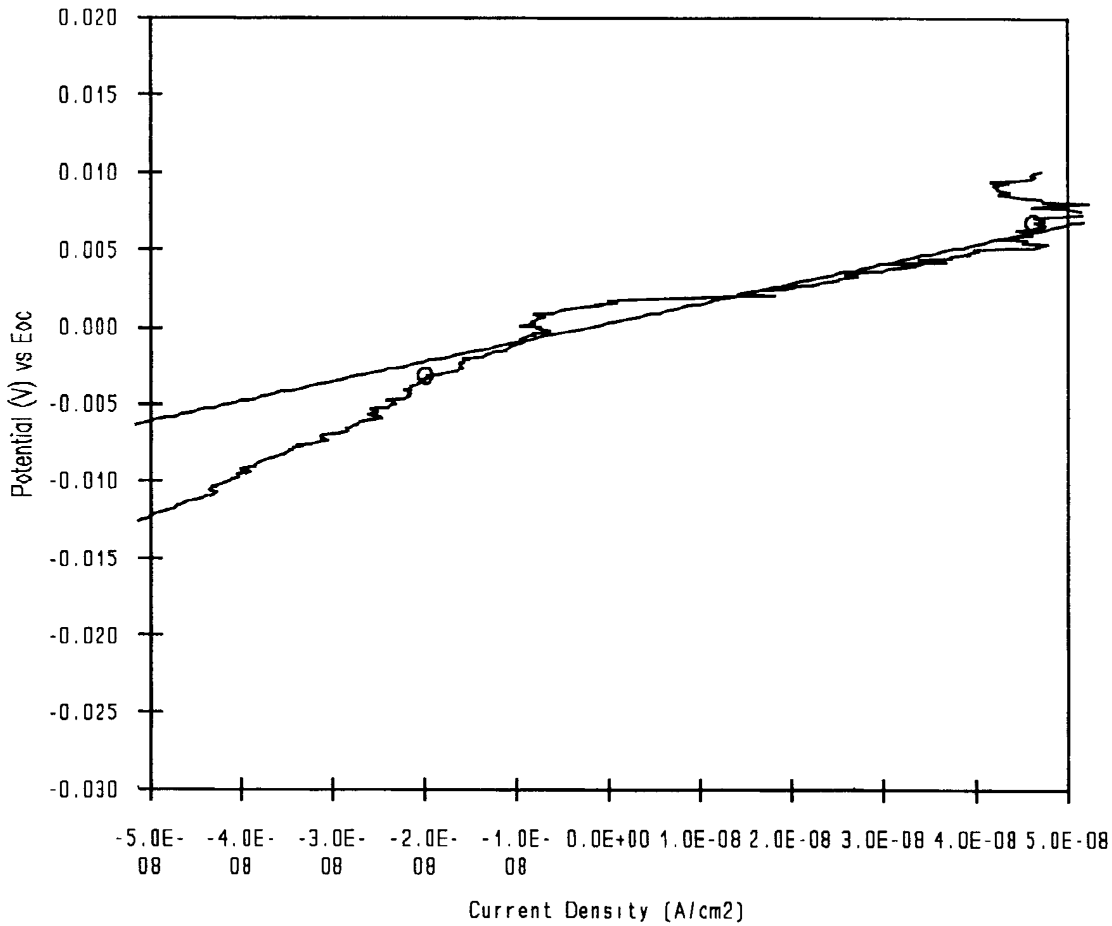

Figure 218. 24 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% BaBor in the coating on solvent cleaned Al in 0.01 M K_2SO_4.

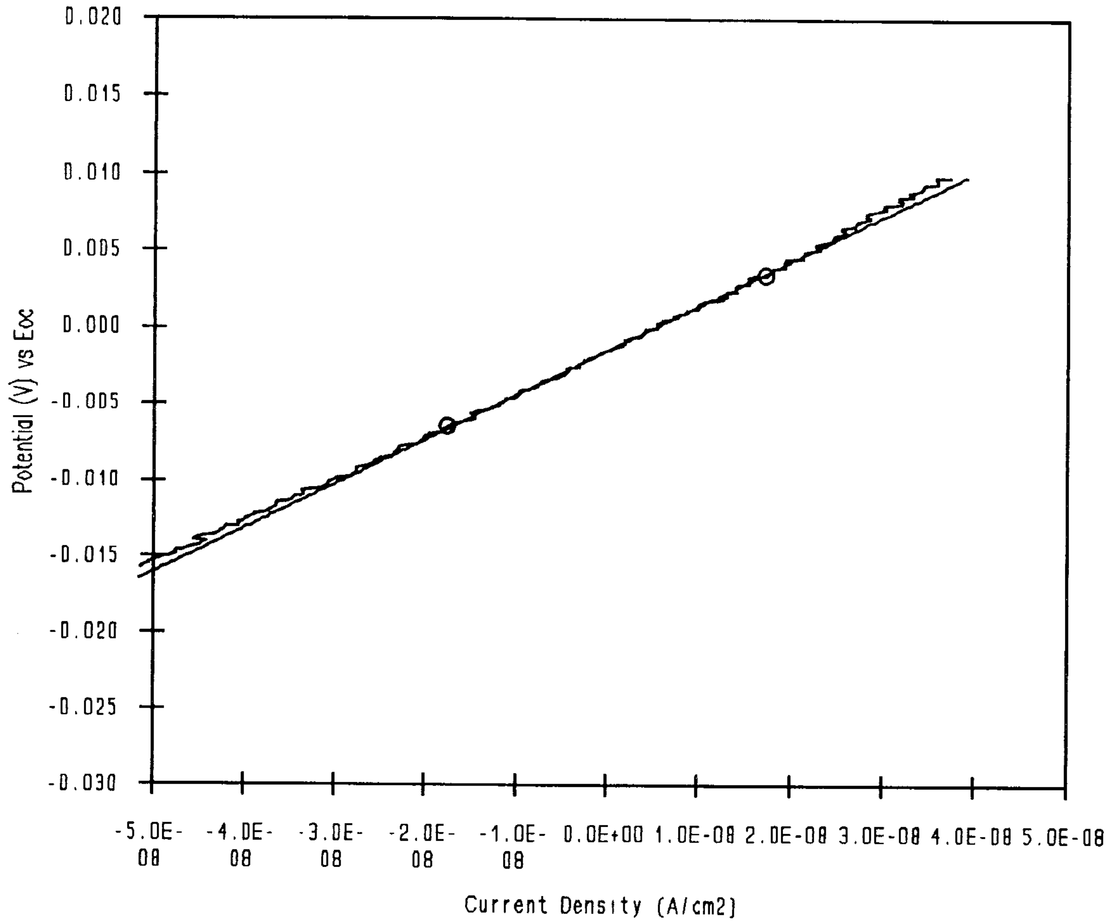

Figure 219. 48 h polarization resistance curve of Epoxy 3 cured 2 h at 100°C with 17% BaBor in the coating on solvent cleaned Al in 0.01 M K_2SO_4.

ZERO DISCHARGE ORGANIC COATINGS
Powder Paint - UV Curable Paint - E-Coat

APPENDIX I

XPS Spectra for the Inhibitor Characterization and Analysis

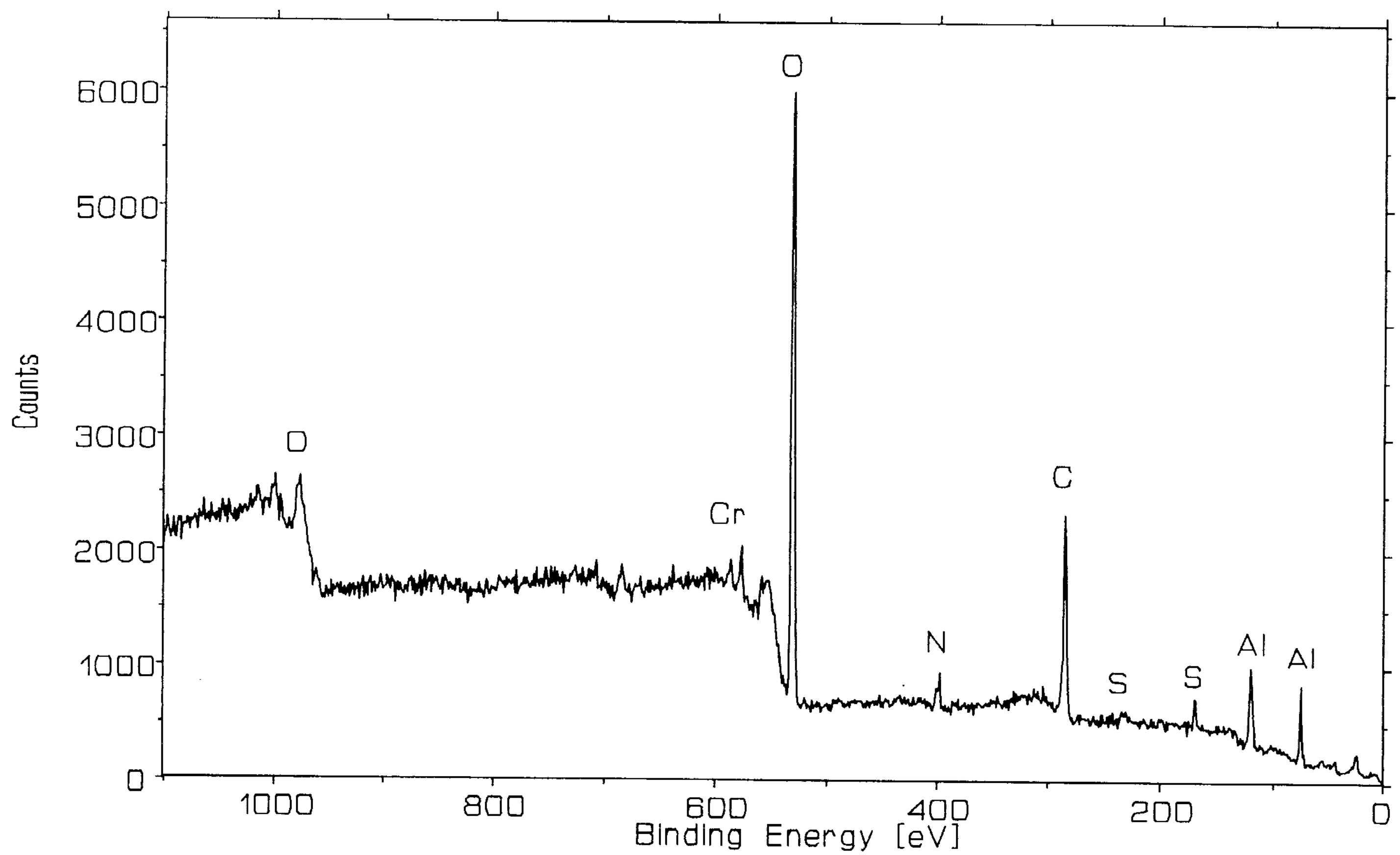

Figure 220. XPS spectrum obtained inside the hole in CCC Al exposed to 0.01 M obtained K_2SO_4 for 48 h.

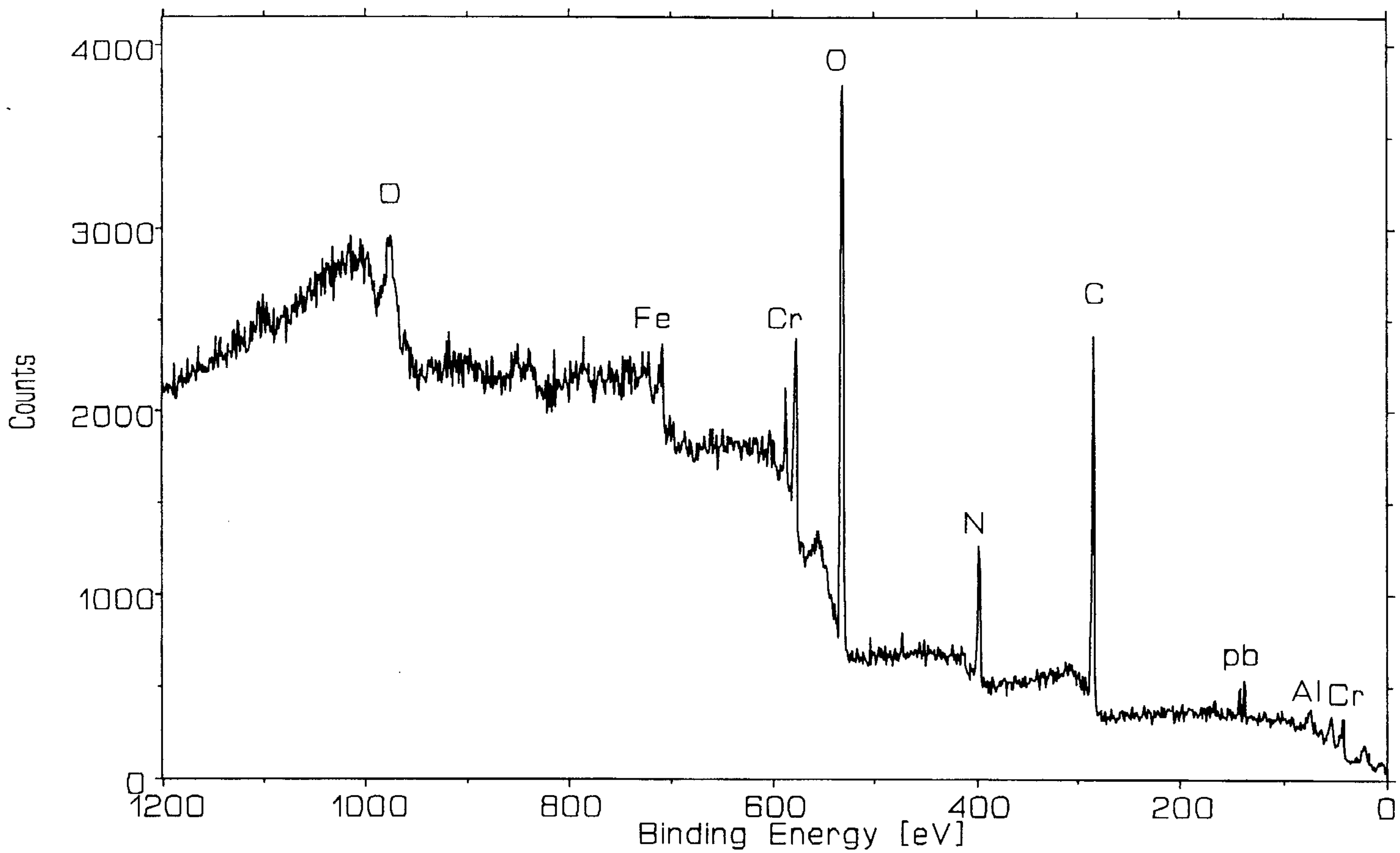

Figure 221. XPS spectrum obtained just outside the hole in CCC Al exposed to 0.01 M obtained K_2SO_4 for 48 h.

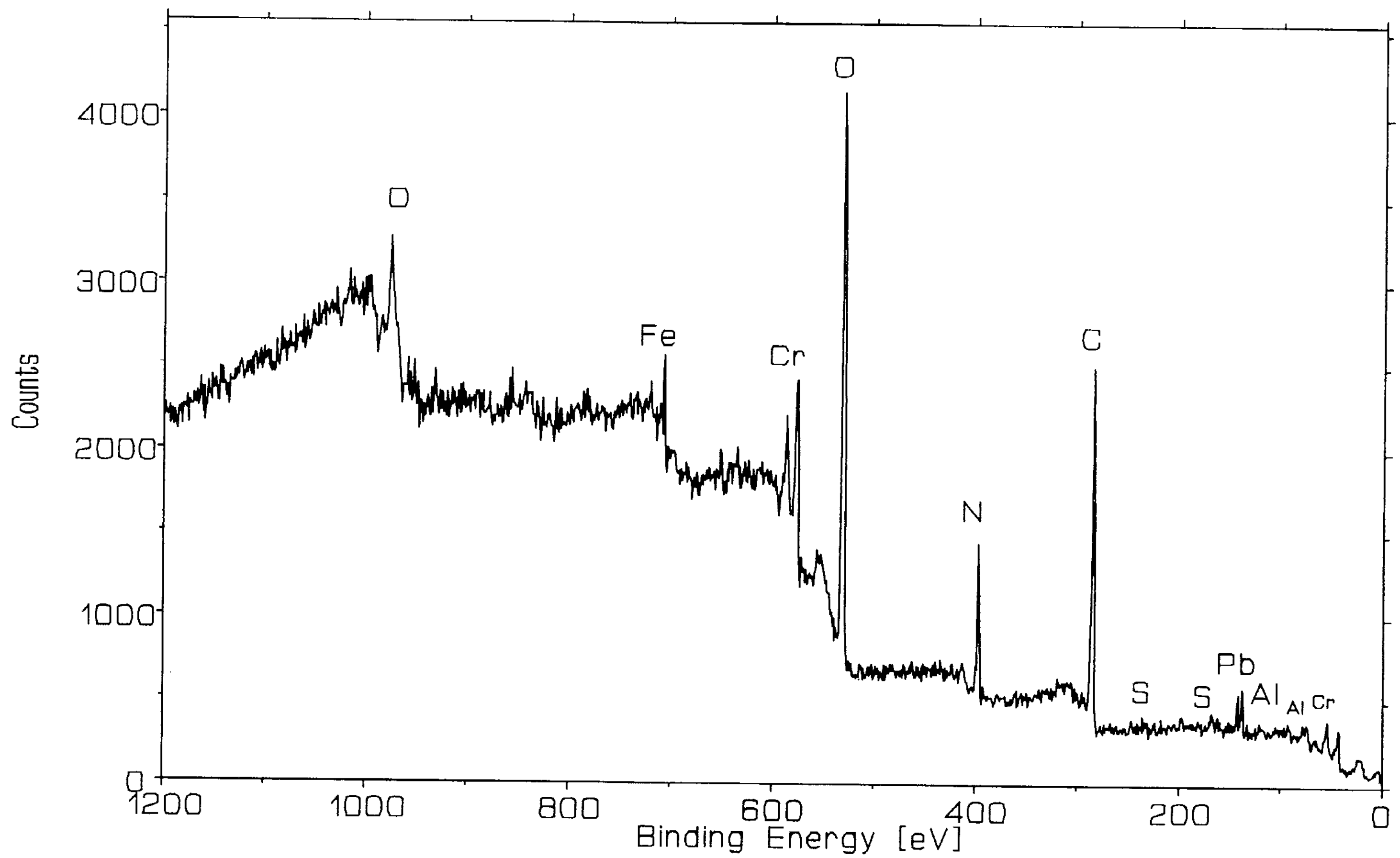

Figure 222. XPS spectrum obtained far from the hole in CCC Al exposed to 0.01 M obtained K_2SO_4 for 48 h.

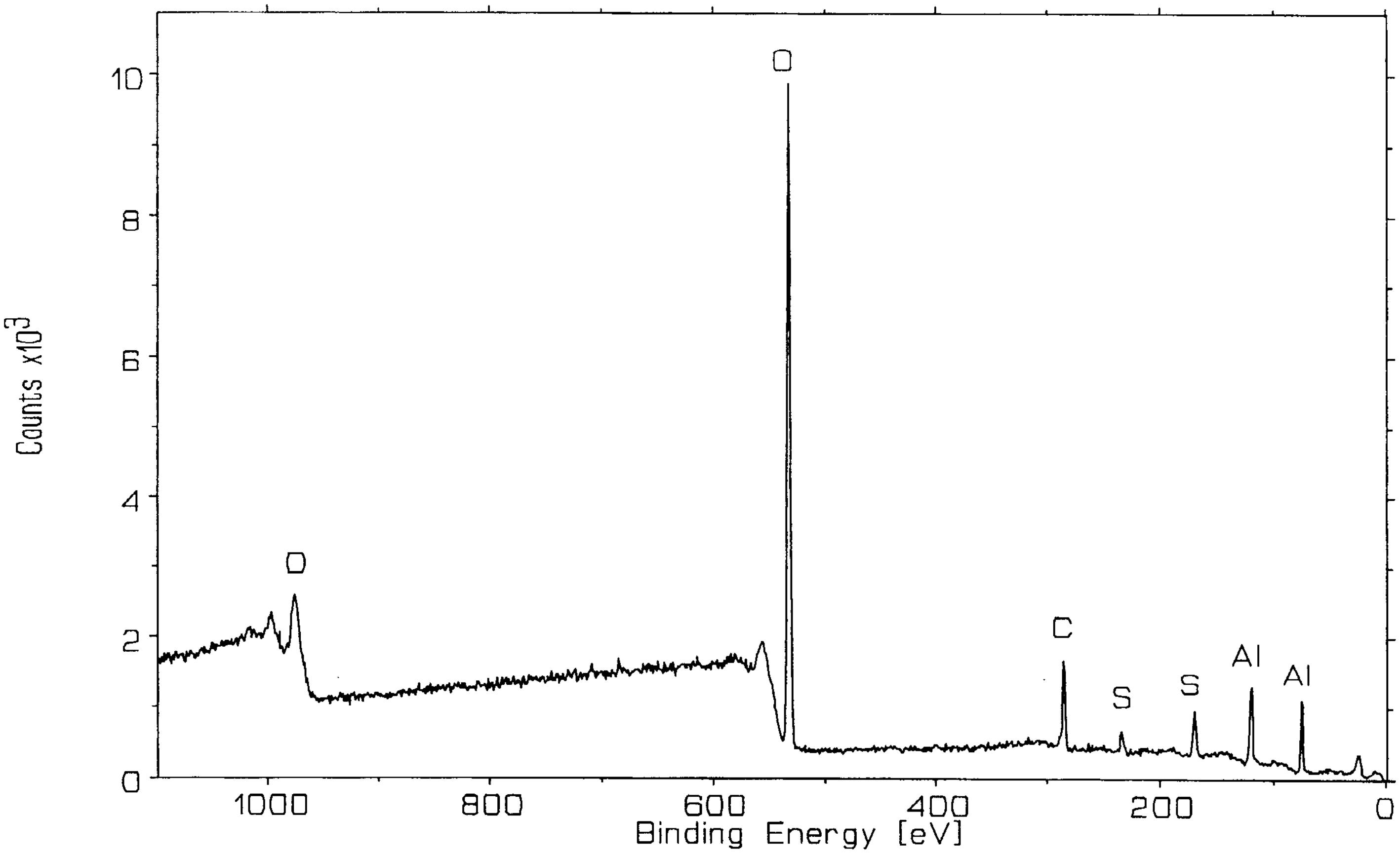

Figure 223. XPS spectrum obtained inside the hole in chemically cleaned Al exposed to 0.01 M obtained K_2SO_4 for 48 h.

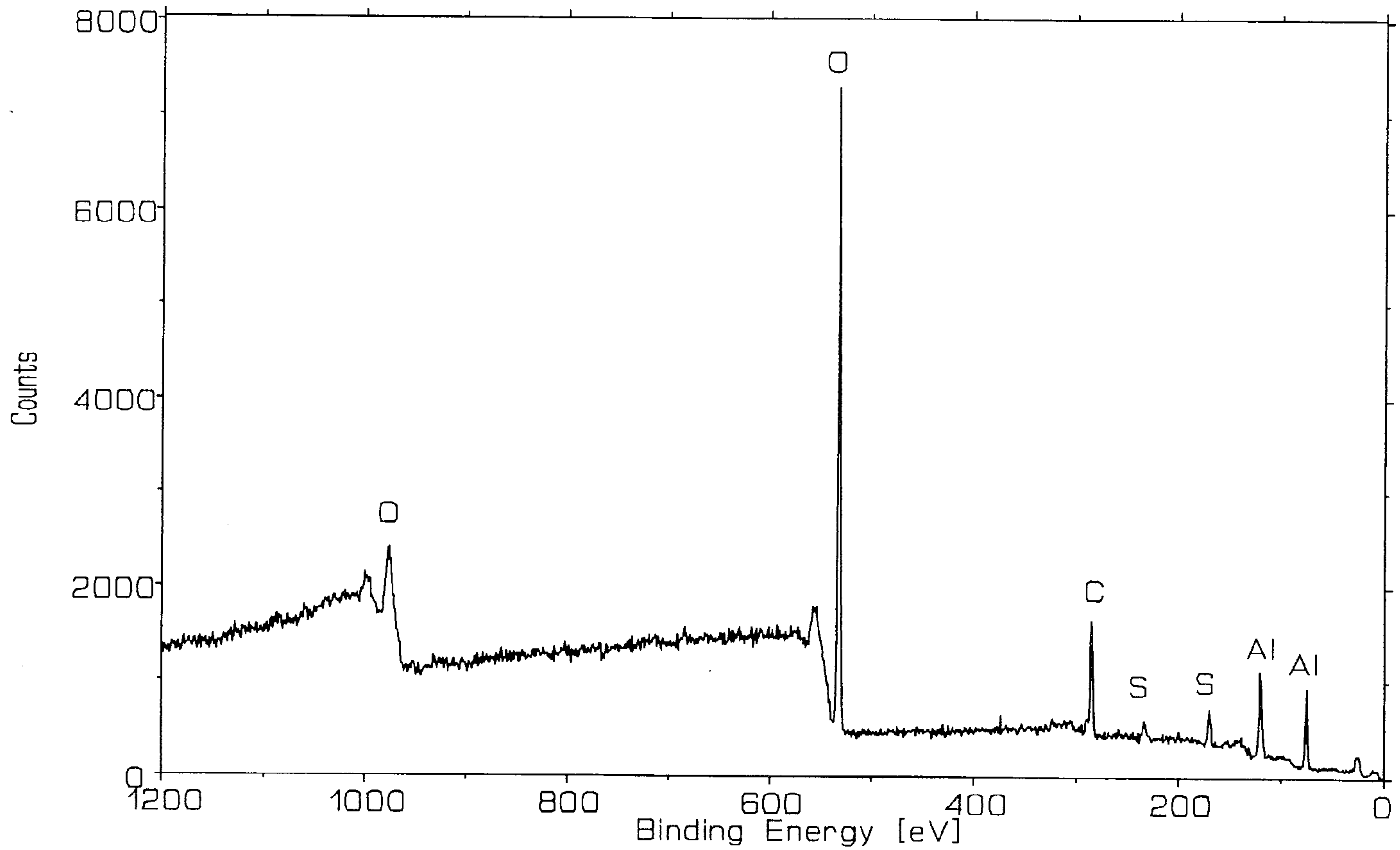

Figure 224. XPS spectrum obtained just outside the hole in chemically cleaned Al exposed to 0.01 M obtained K_2SO_4 for 48 h.

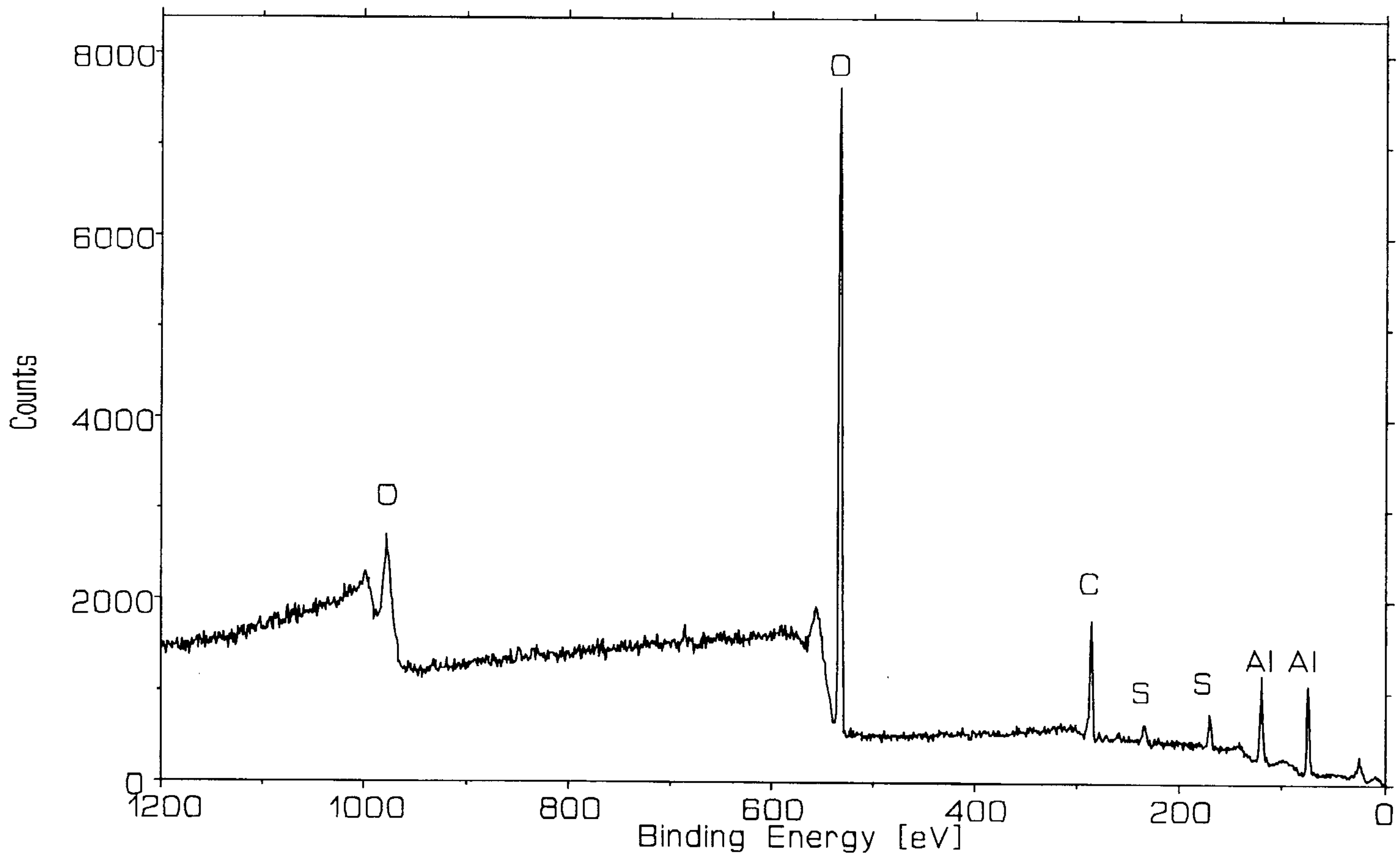

Figure 225. XPS spectrum obtained far from the hole in chemically cleaned Al exposed to 0.01 M K_2SO_4 for 48 h.

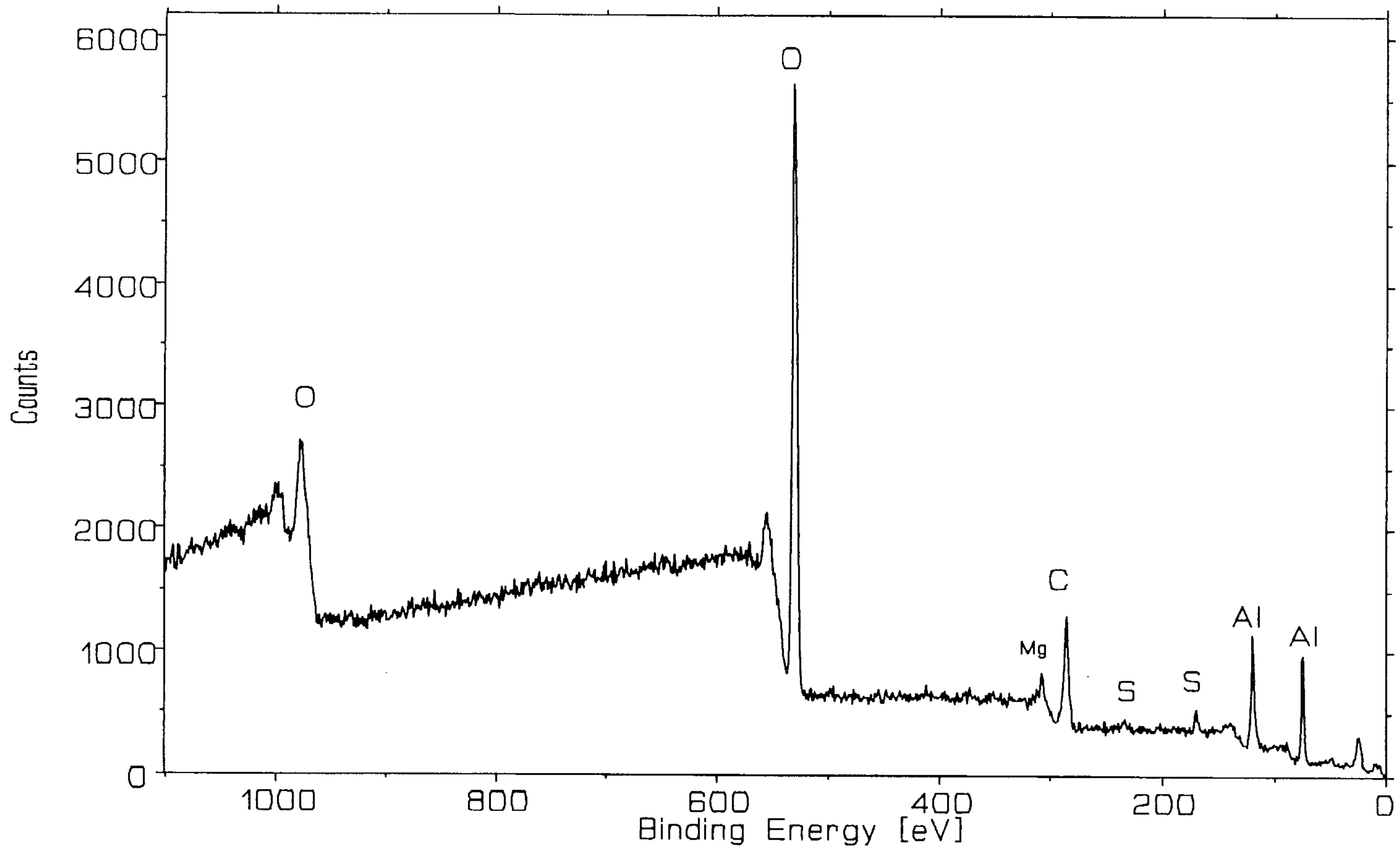

Figure 226. XPS spectrum obtained inside the hole in solvent cleaned Al exposed to 0.01 M K_2SO_4 for 48 h.

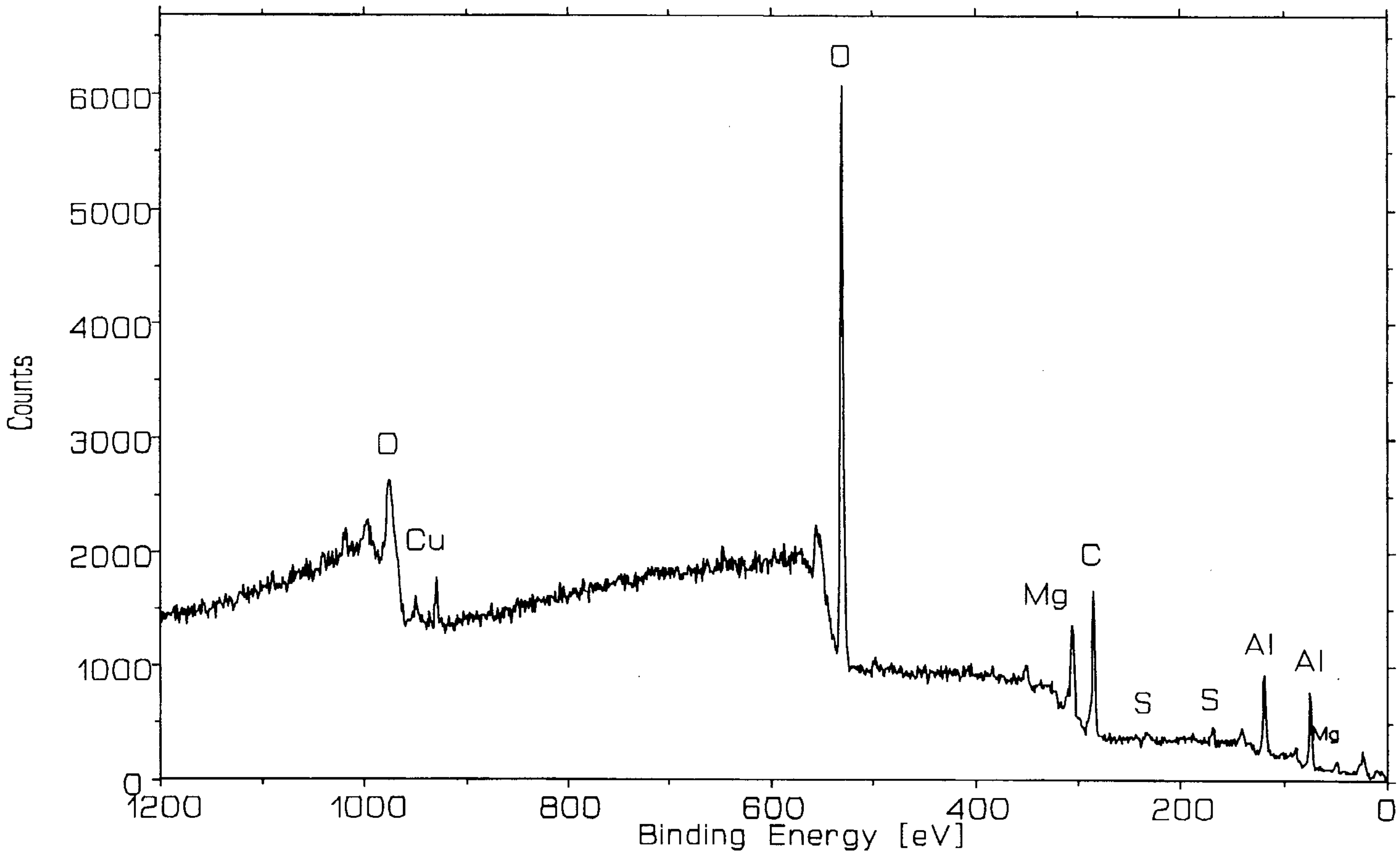

Figure 227. XPS spectrum obtained just outside the hole in solvent cleaned Al exposed to 0.01 M K_2SO_4 for 48 h.

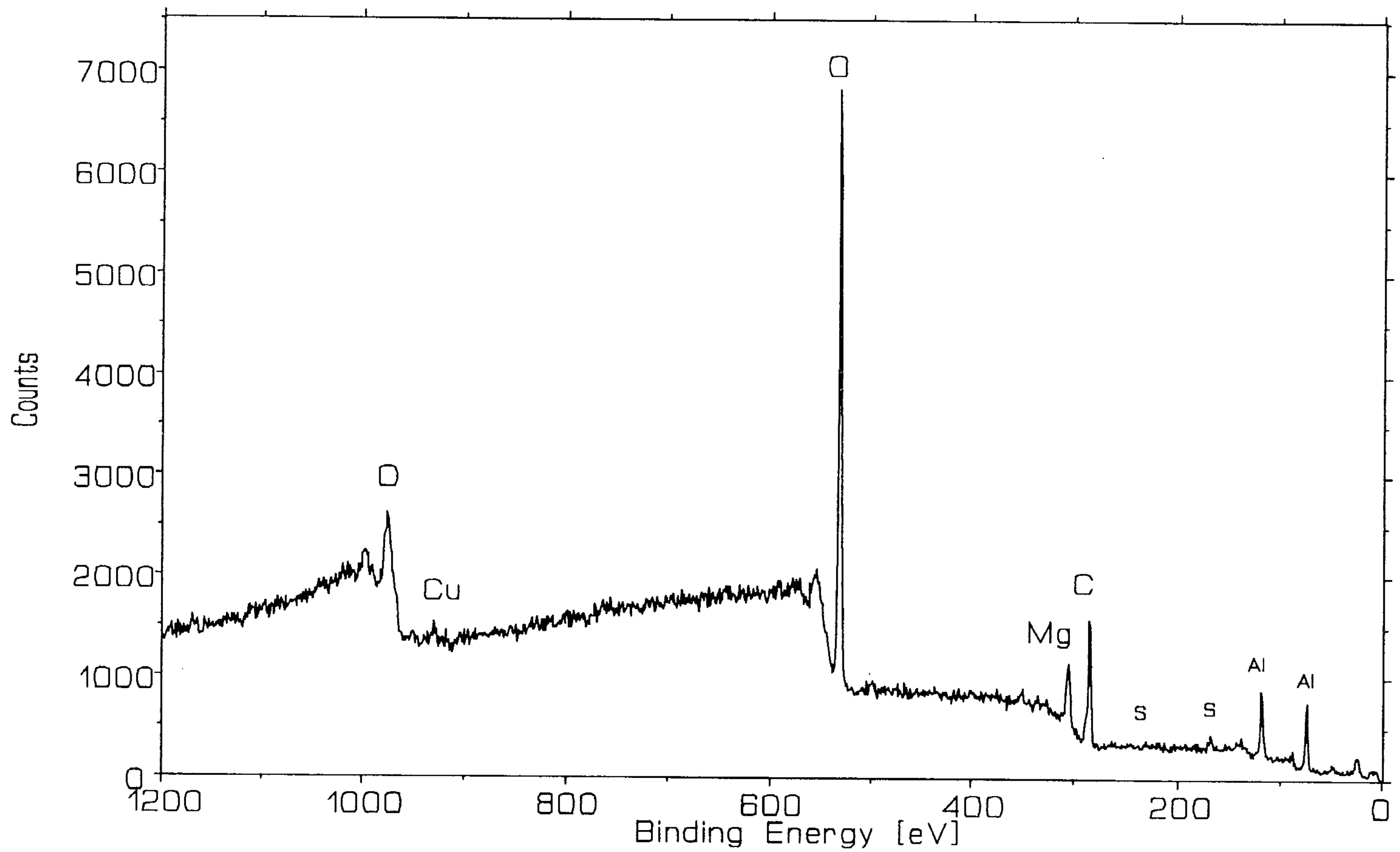

Figure 228. XPS spectrum obtained far from the hole in solvent cleaned Al exposed to 0.01 M K_2SO_4 for 48 h.

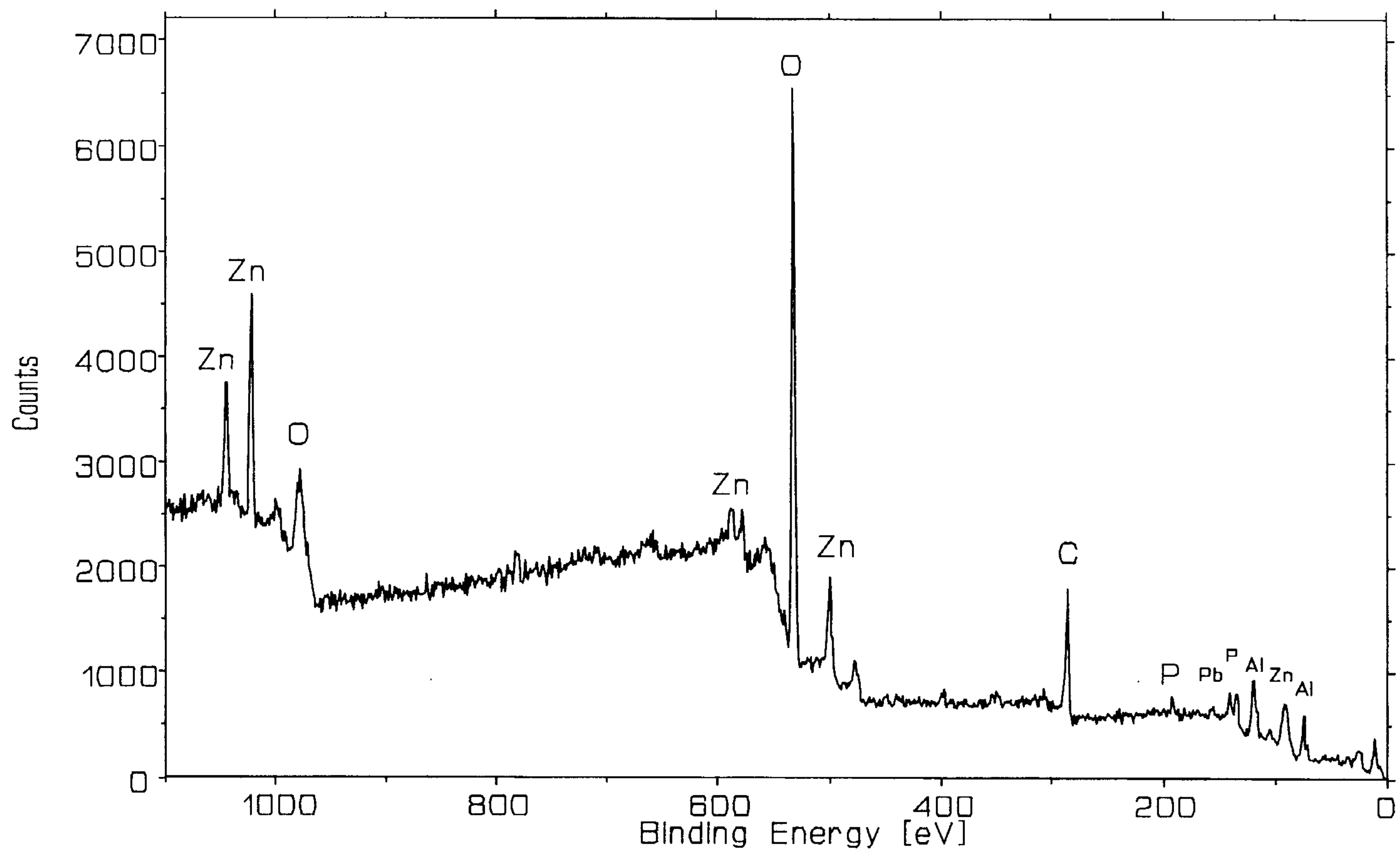

Figure 229. XPS spectrum obtained inside the hole in CCC Al exposed to MPSi saturated 0.01 M K_2SO_4 for 48 h.

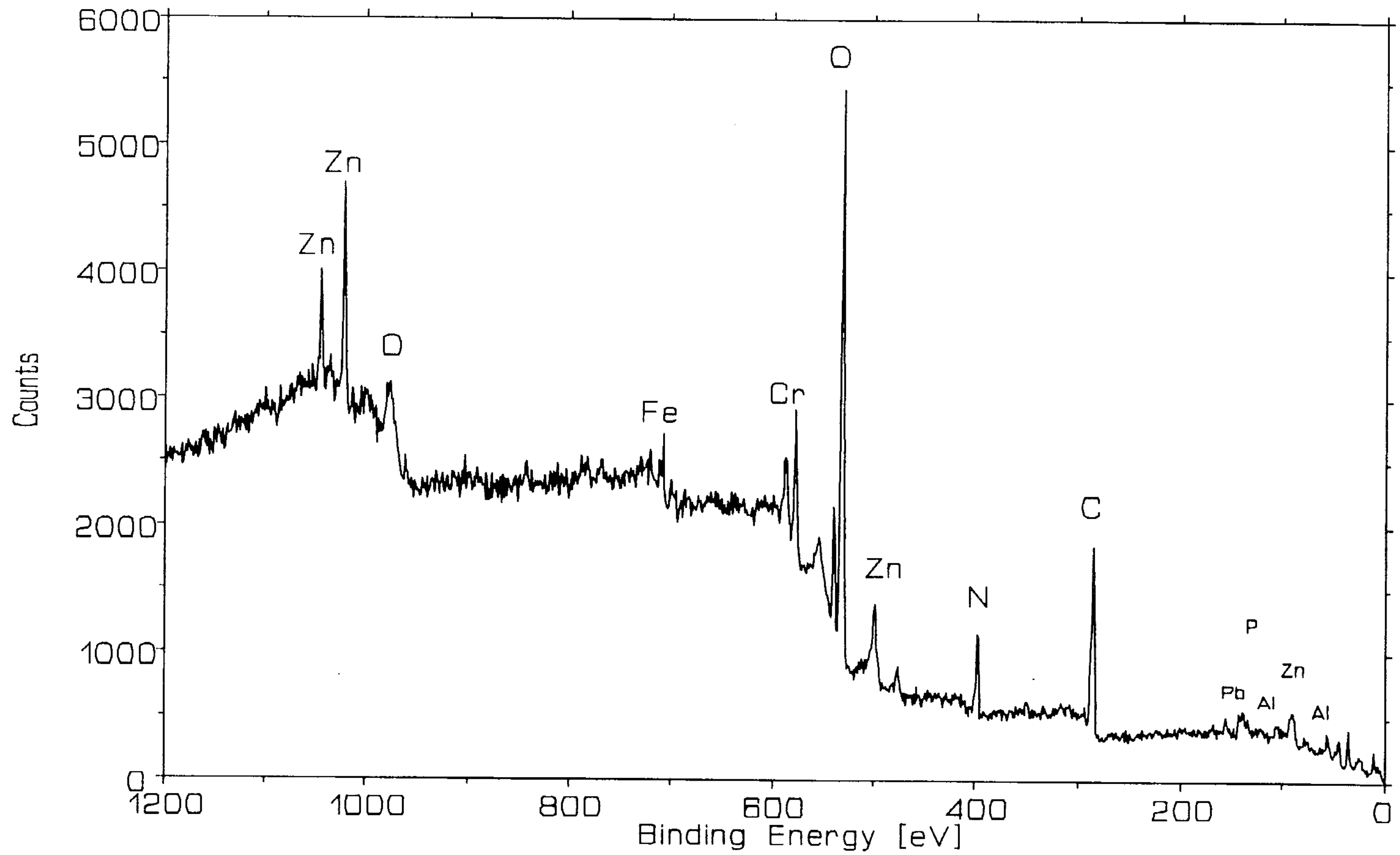

Figure 230. XPS spectrum obtained just outside the hole in CCC Al exposed to MPSi saturated 0.01 M K_2SO_4 for 48 h.

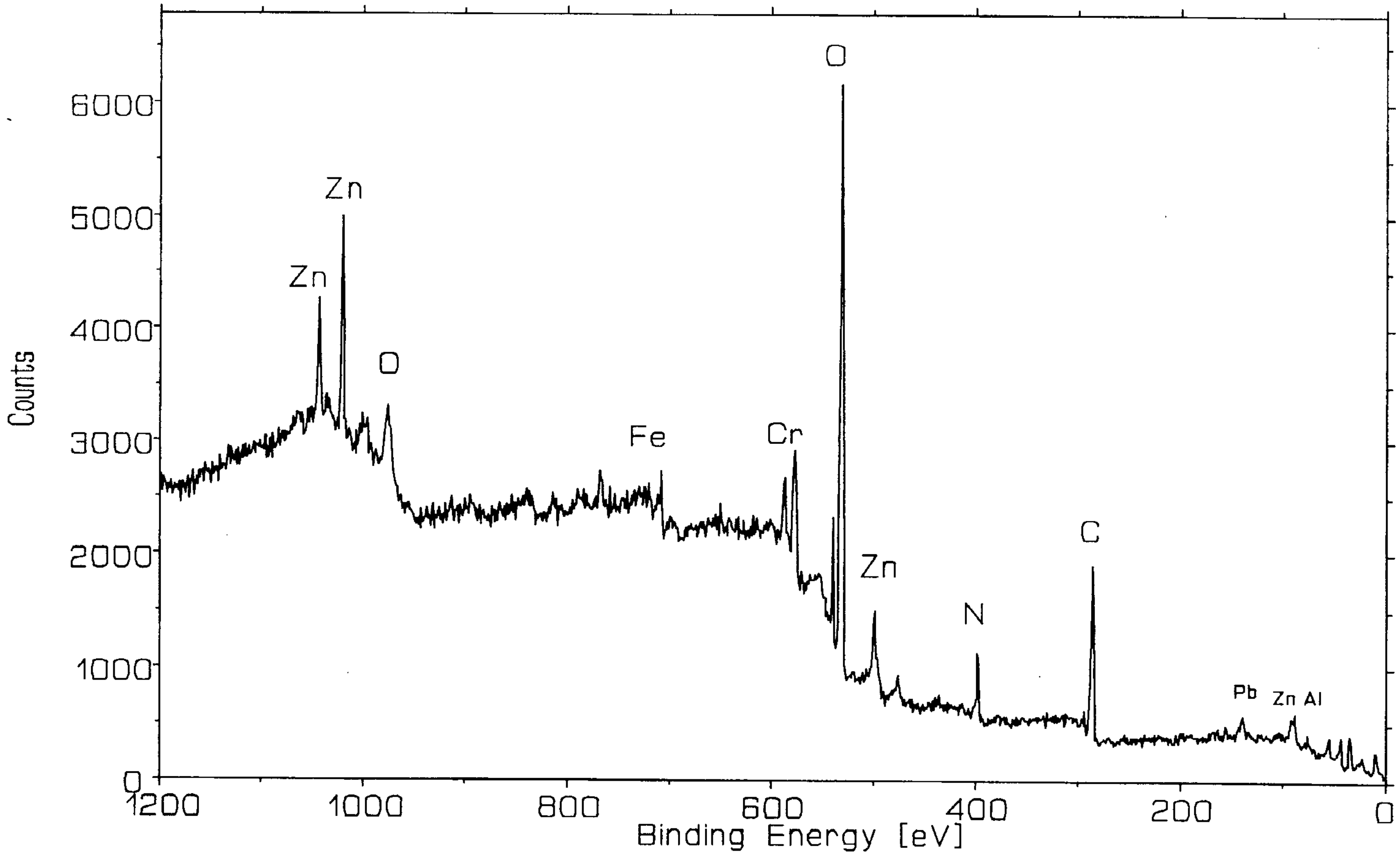

Figure 231. XPS spectrum obtained far from the hole in CCC Al exposed to MPSi saturated 0.01 M K_2SO_4 for 48 h.

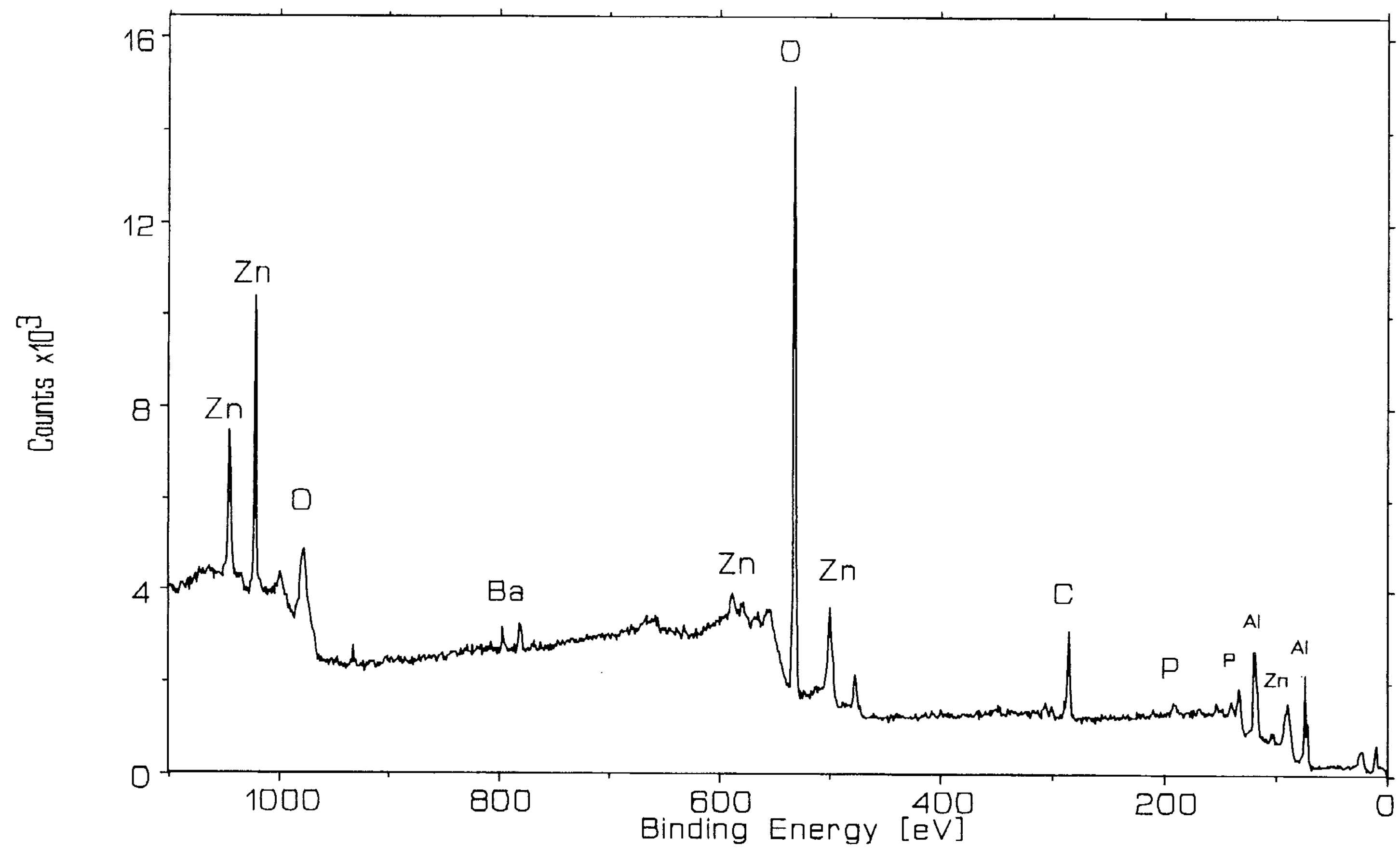

Figure 232. XPS spectrum obtained inside the hole in chemically cleaned Al exposed to MPSi saturated 0.01 M K_2SO_4 for 48 h.

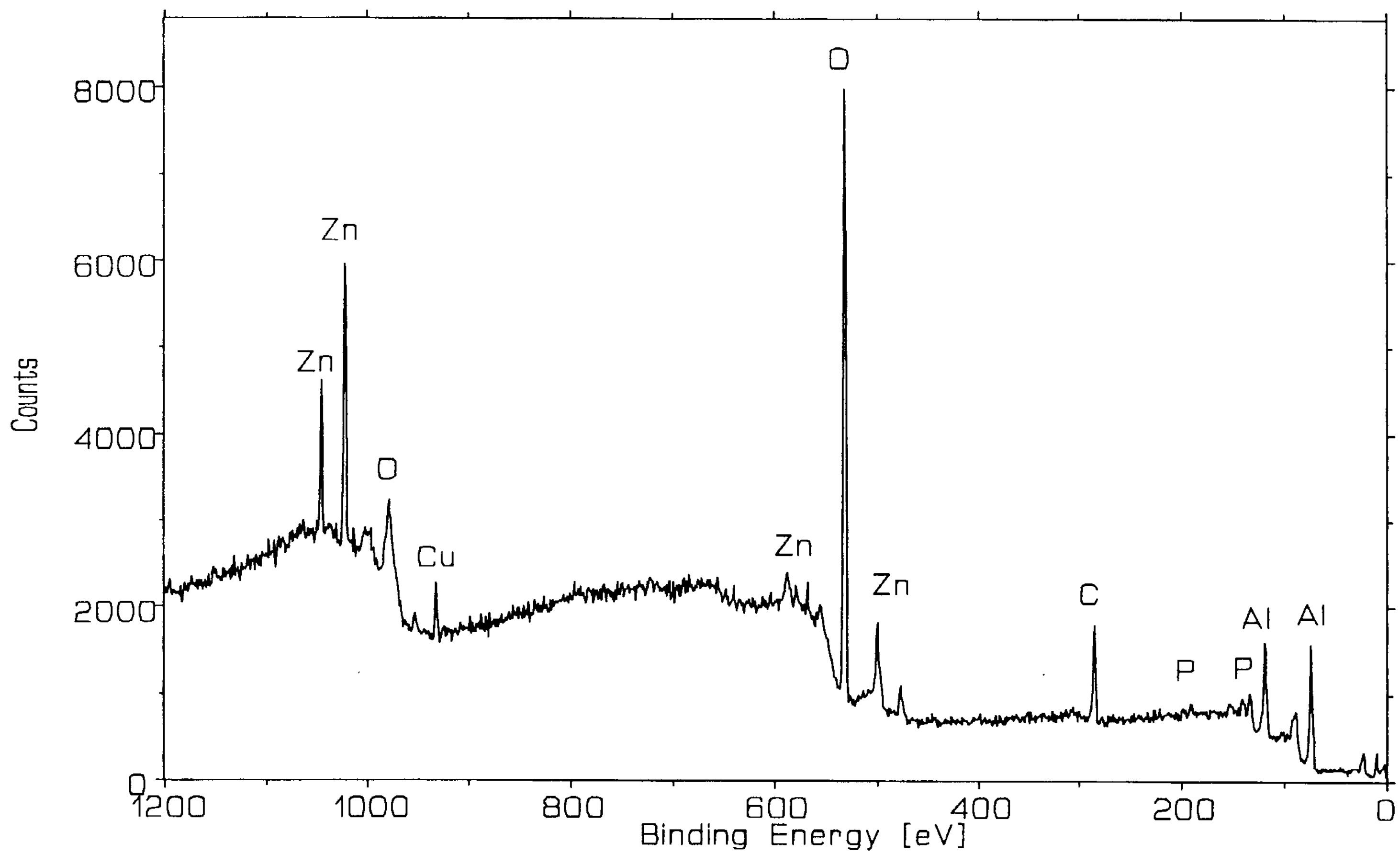

Figure 233. XPS spectrum obtained just outside the hole in chemically cleaned Al exposed to MPSi saturated 0.01 M K_2SO_4 for 48 h.

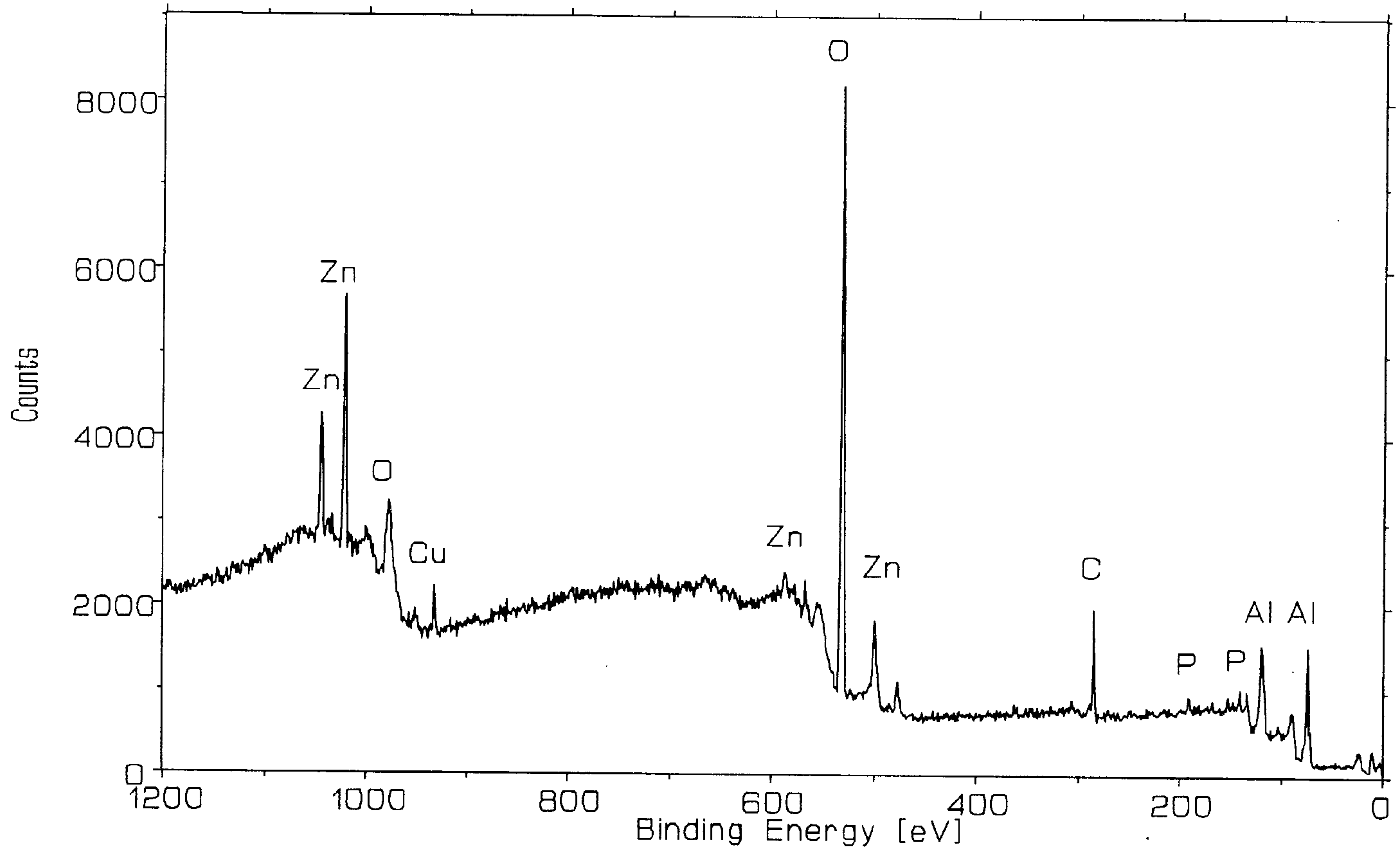

Figure 234. XPS spectrum obtained far from the hole in chemically cleaned Al exposed to MPSi saturated 0.01 M K_2SO_4 for 48 h.

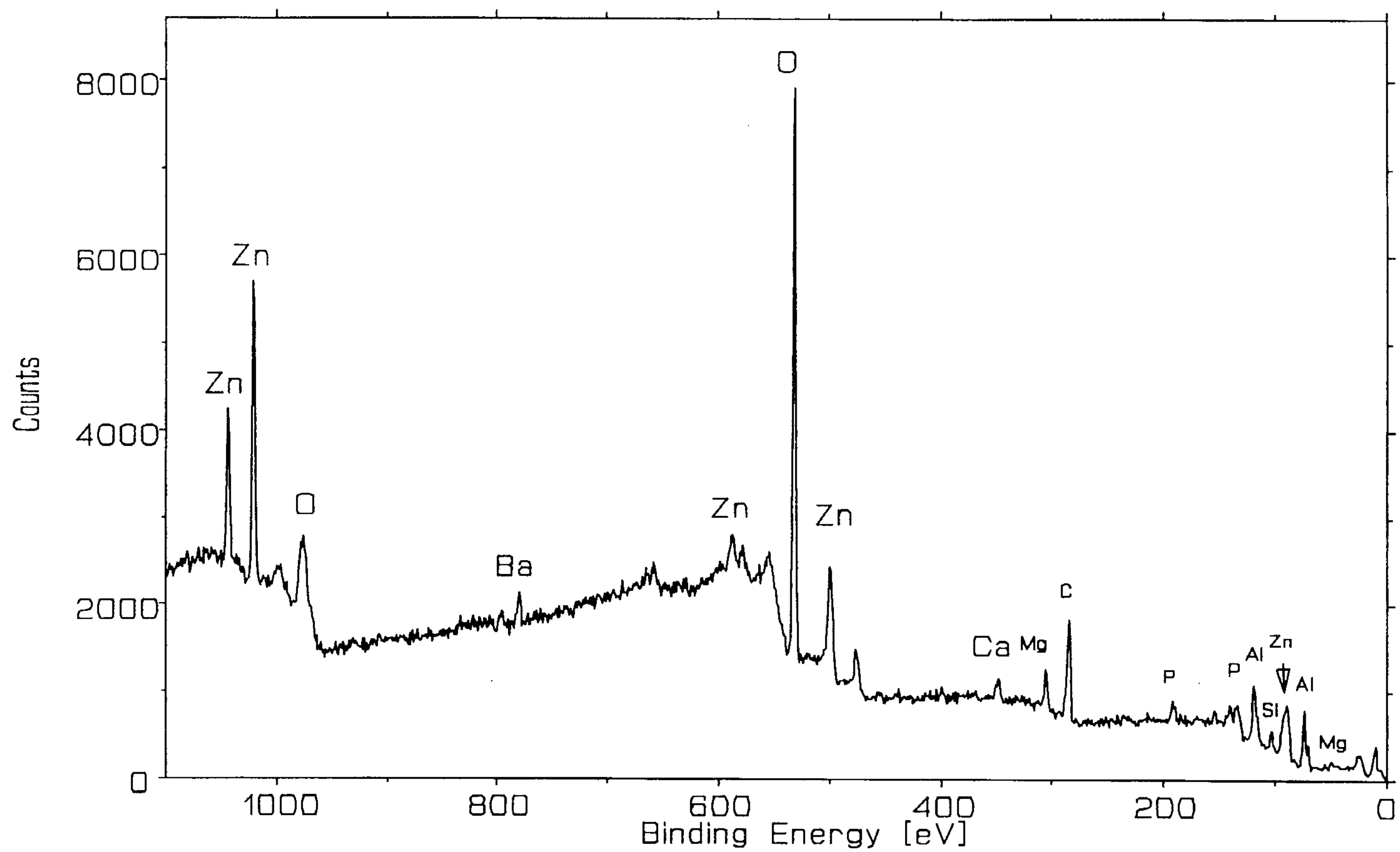

Figure 235. XPS spectrum obtained inside the hole in solvent cleaned Al exposed to MPSi saturated 0.01 M K_2SO_4 for 48 h.

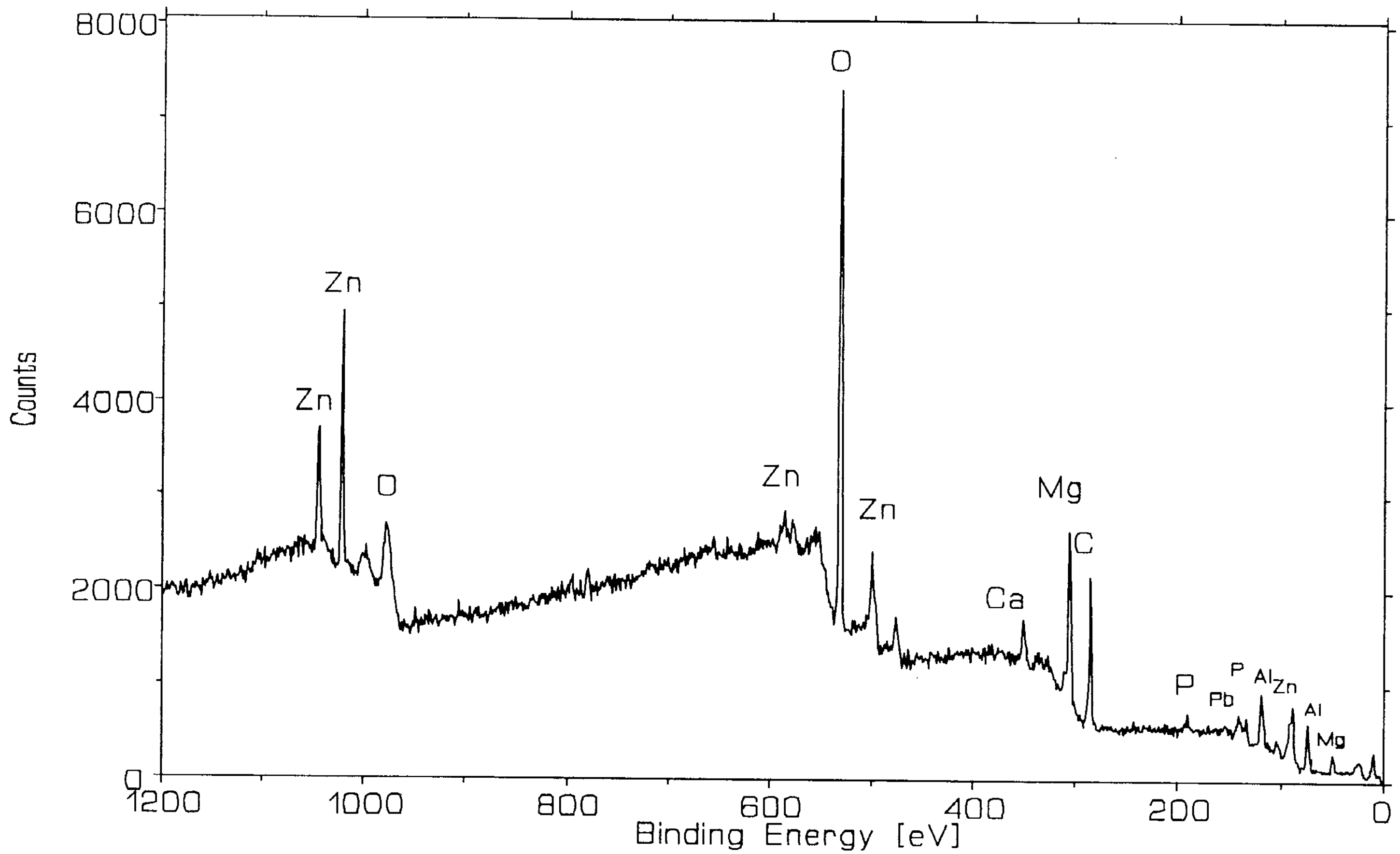

Figure 236. XPS spectrum obtained just outside the hole in solvent cleaned Al exposed to MPSi saturated 0.01 M K_2SO_4 for 48 h.

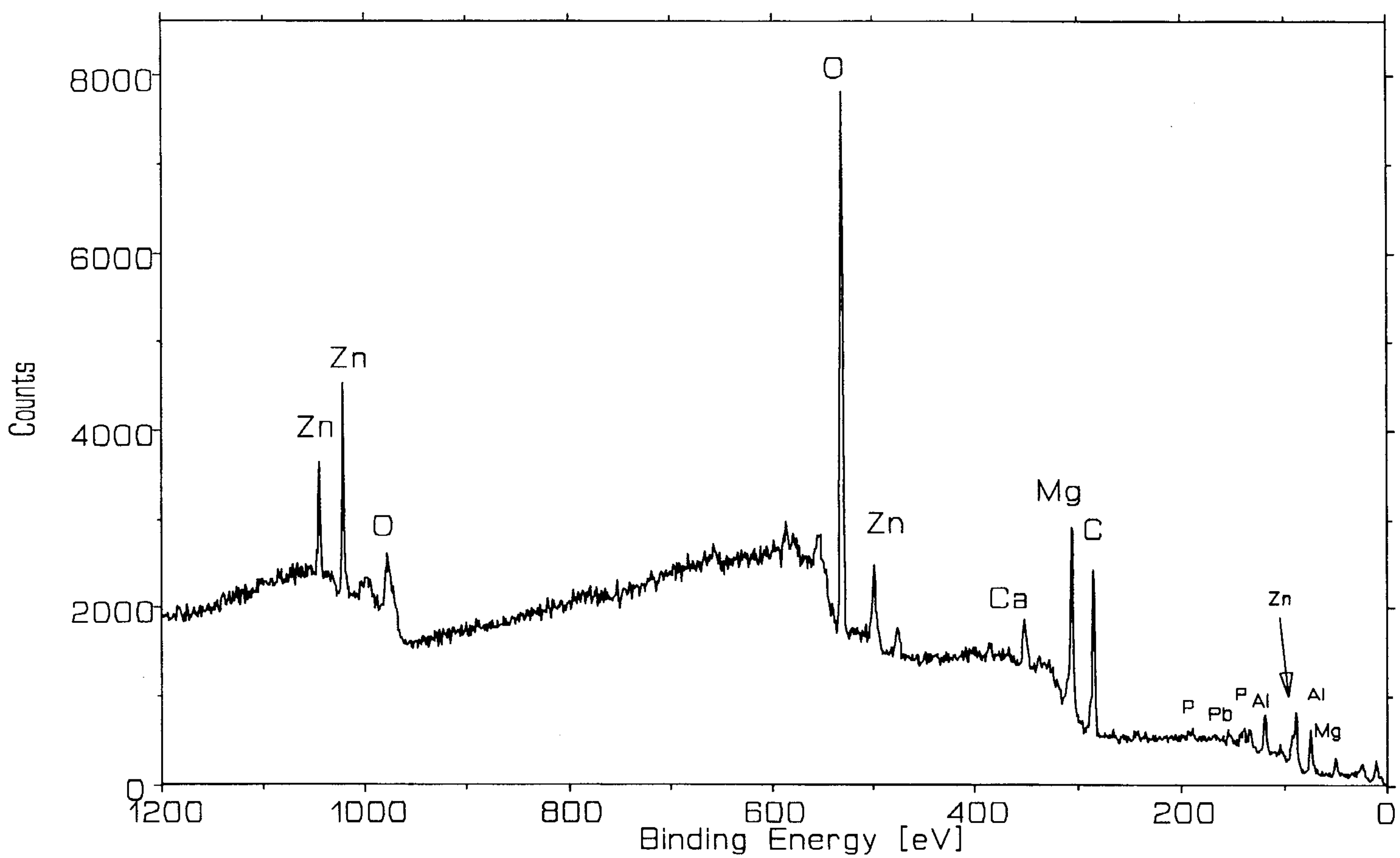

Figure 237. XPS spectrum obtained far from the hole in solvent cleaned Al exposed to MPSi saturated 0.01 M K_2SO_4 for 48 h.

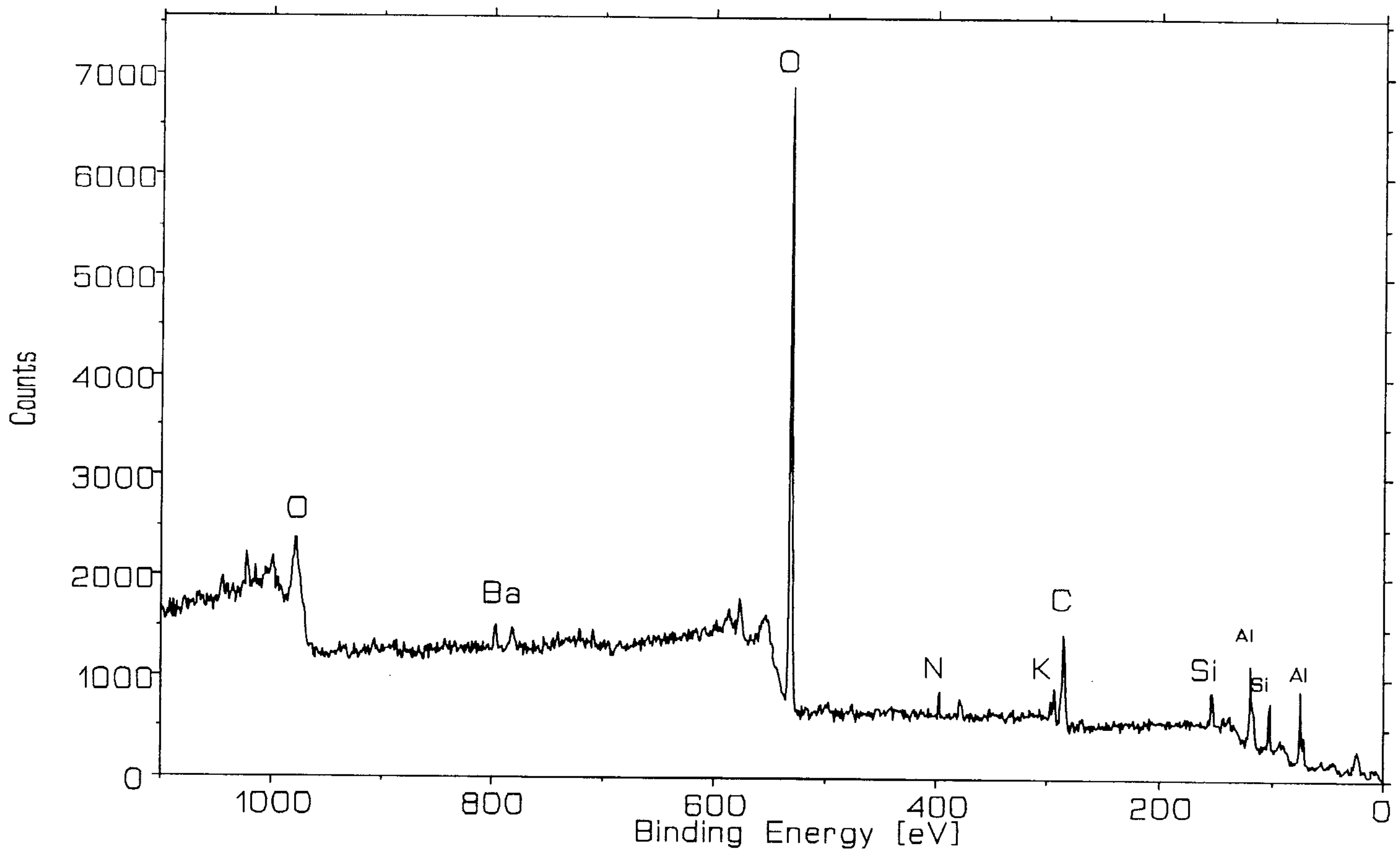

Figure 238. XPS spectrum obtained inside the hole in CCC Al exposed to BaBor saturated 0.01 M K_2SO_4 for 48 h.

ZDOC/95FINAL/APP

ZERO DISCHARGE ORGANIC COATINGS
Powder Paint - UV Curable Paint - E-Coat

APPENDIX J

SEM Elemental Maps for the Inhibitor Characterization and Analysis

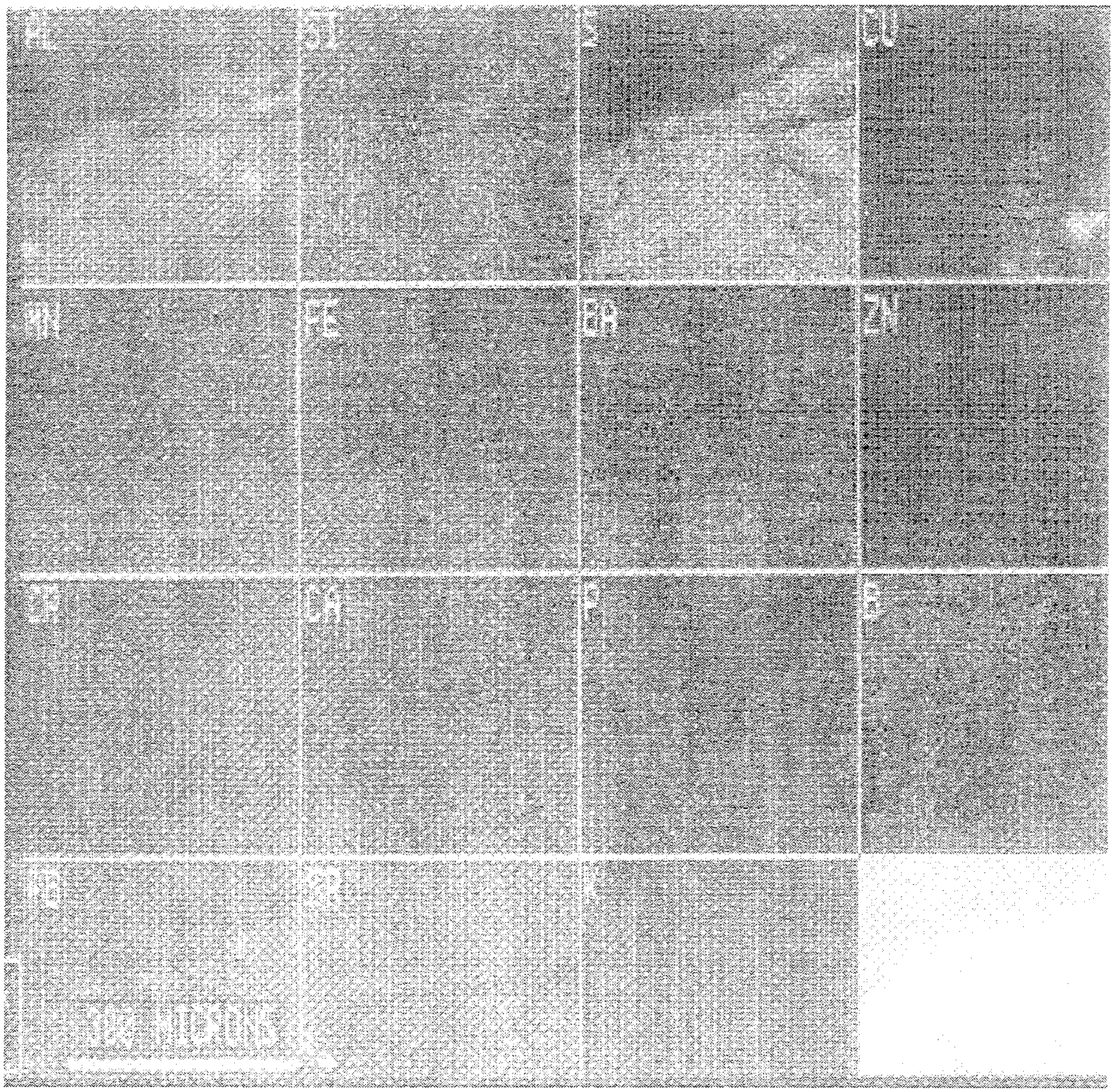

Figure 271. SEM elemental maps showing a cross sectional view of the bottom of an 800 μm diameter defect in an Epoxy 1 coated CCC Al panel exposed to 0.01 M K_2SO_4 for 2 months.

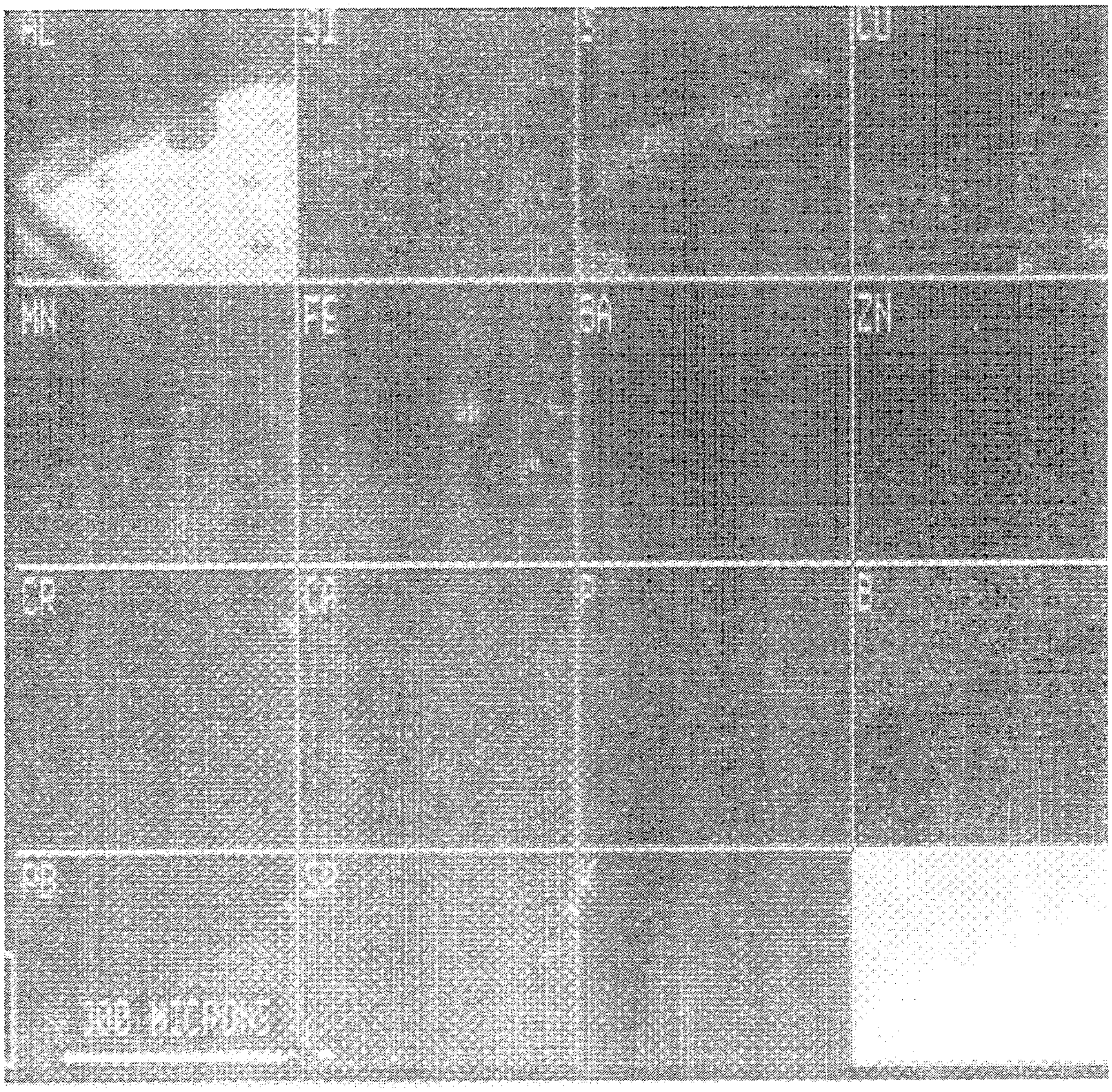

Figure 272. SEM elemental maps showing a cross sectional view of the side of an 800 μm diameter defect in an Epoxy 1 coated CCC Al panel exposed to 0.01 M K_2SO_4 for 2 months.

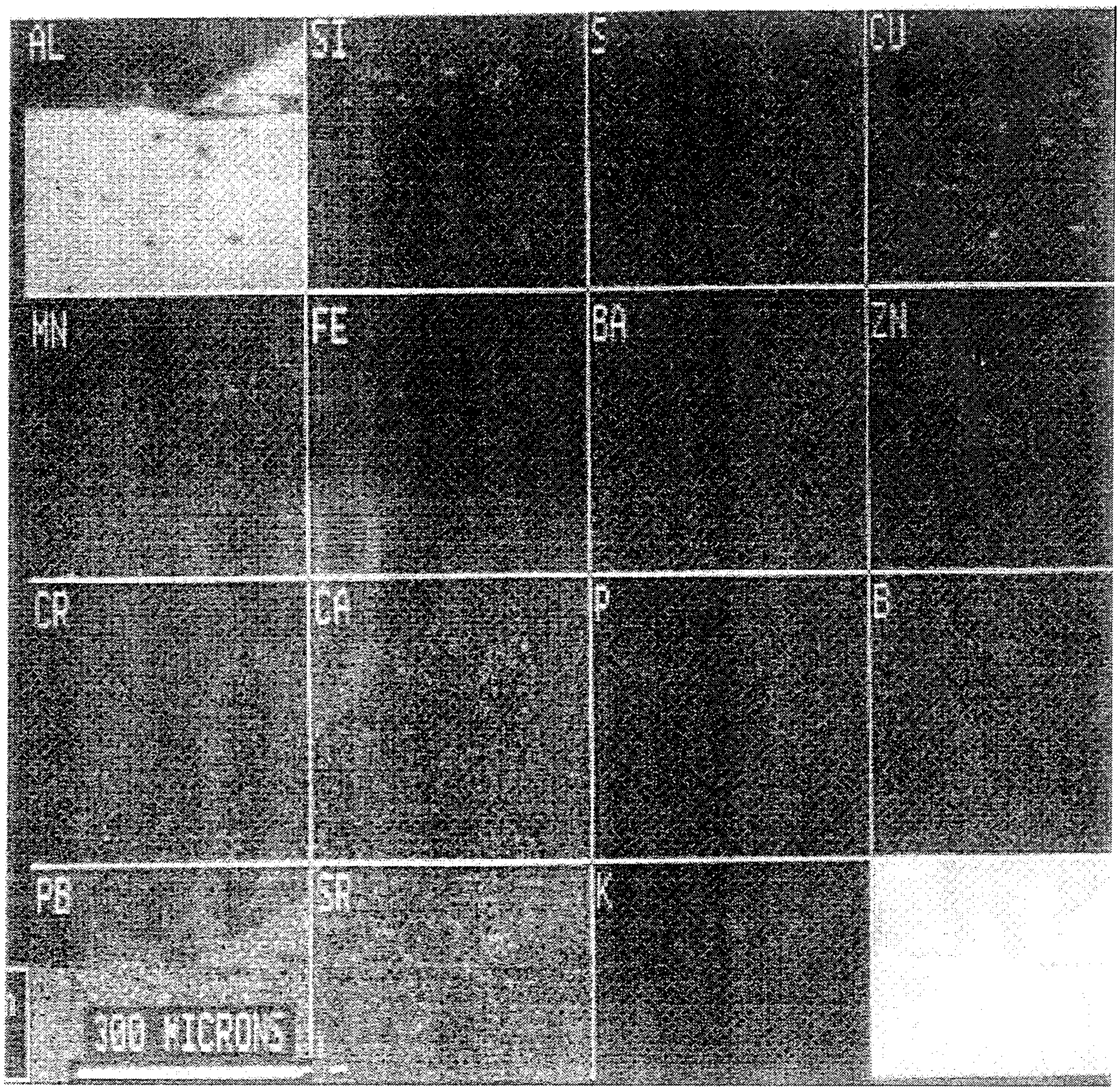

Figure 273. SEM elemental maps showing a cross sectional view of the bottom of an 800 μm diameter defect in an Epoxy 1 coated CCC Al panel exposed to MPSi saturated 0.01 M K_2SO_4 for 2 months.

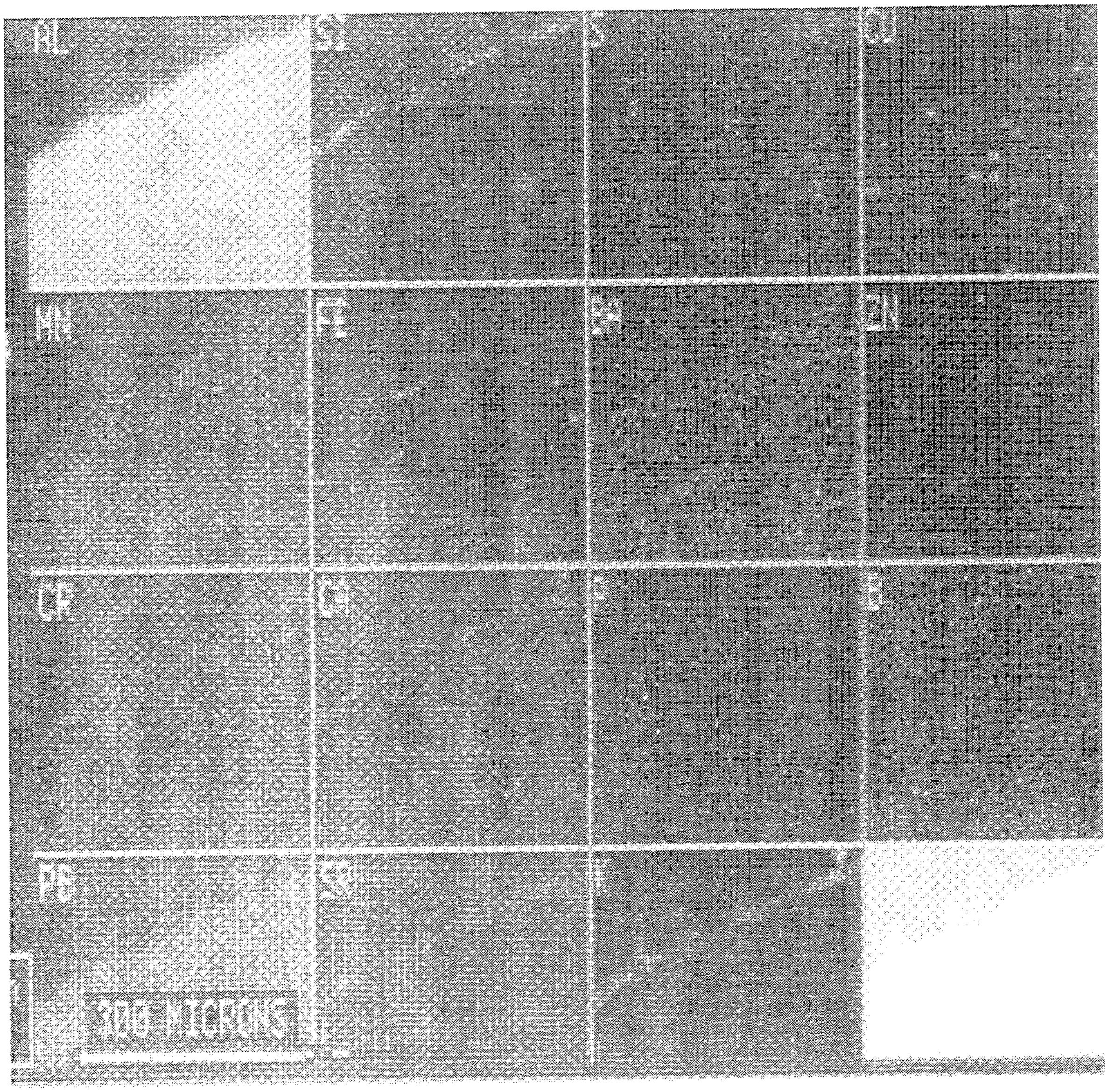

Figure 274. SEM elemental maps showing a cross sectional view of the side of an 800 μm diameter defect in an Epoxy 1 coated CCC Al panel exposed to MPSi saturated 0.01 M K_2SO_4 for 2 months.

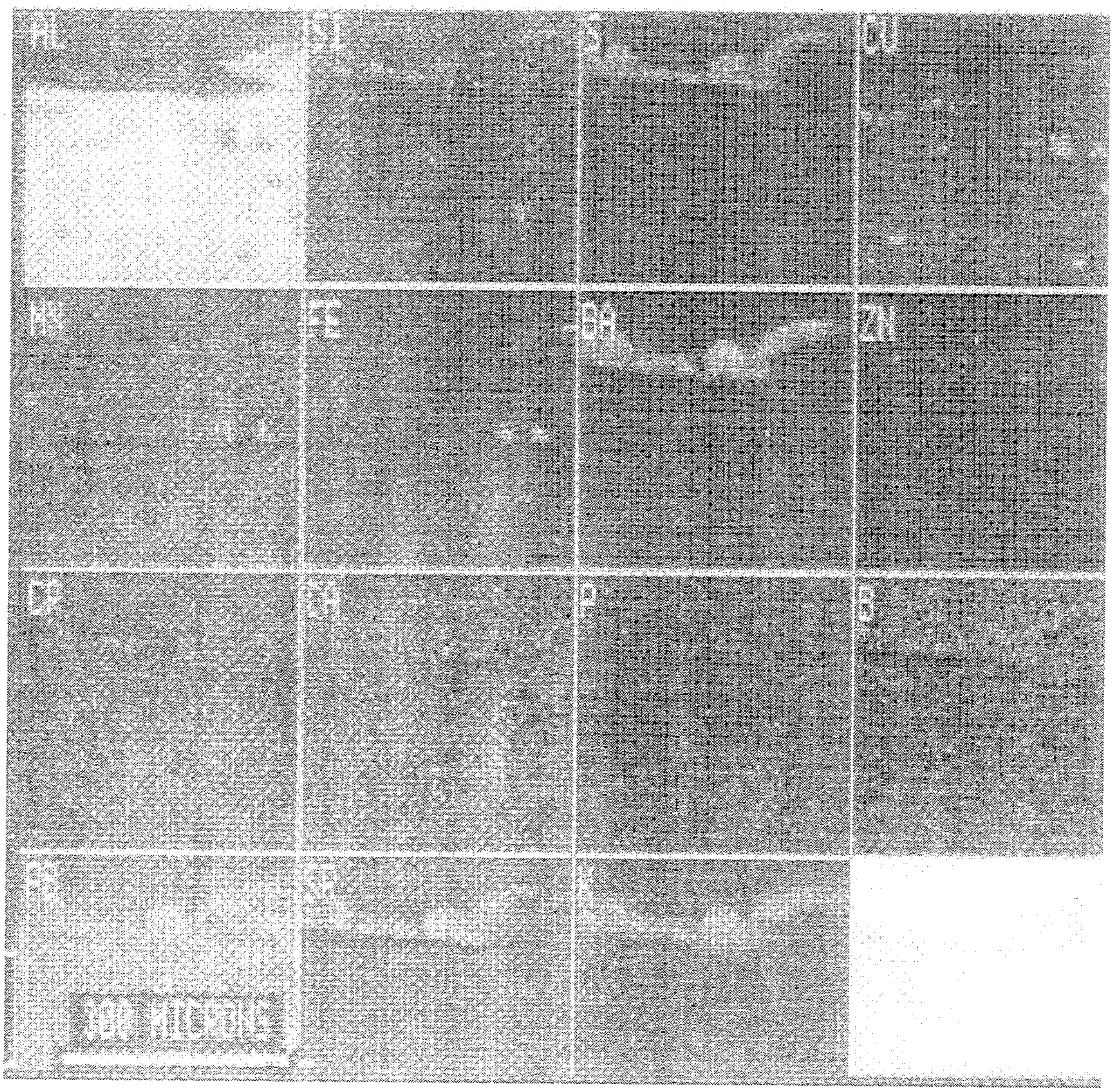

Figure 275. SEM elemental maps showing a cross sectional view of the bottom of an 800 μm diameter defect in an Epoxy 1 coated CCC Al panel exposed to BaBor saturated 0.01 M K_2SO_4 for 2 months.

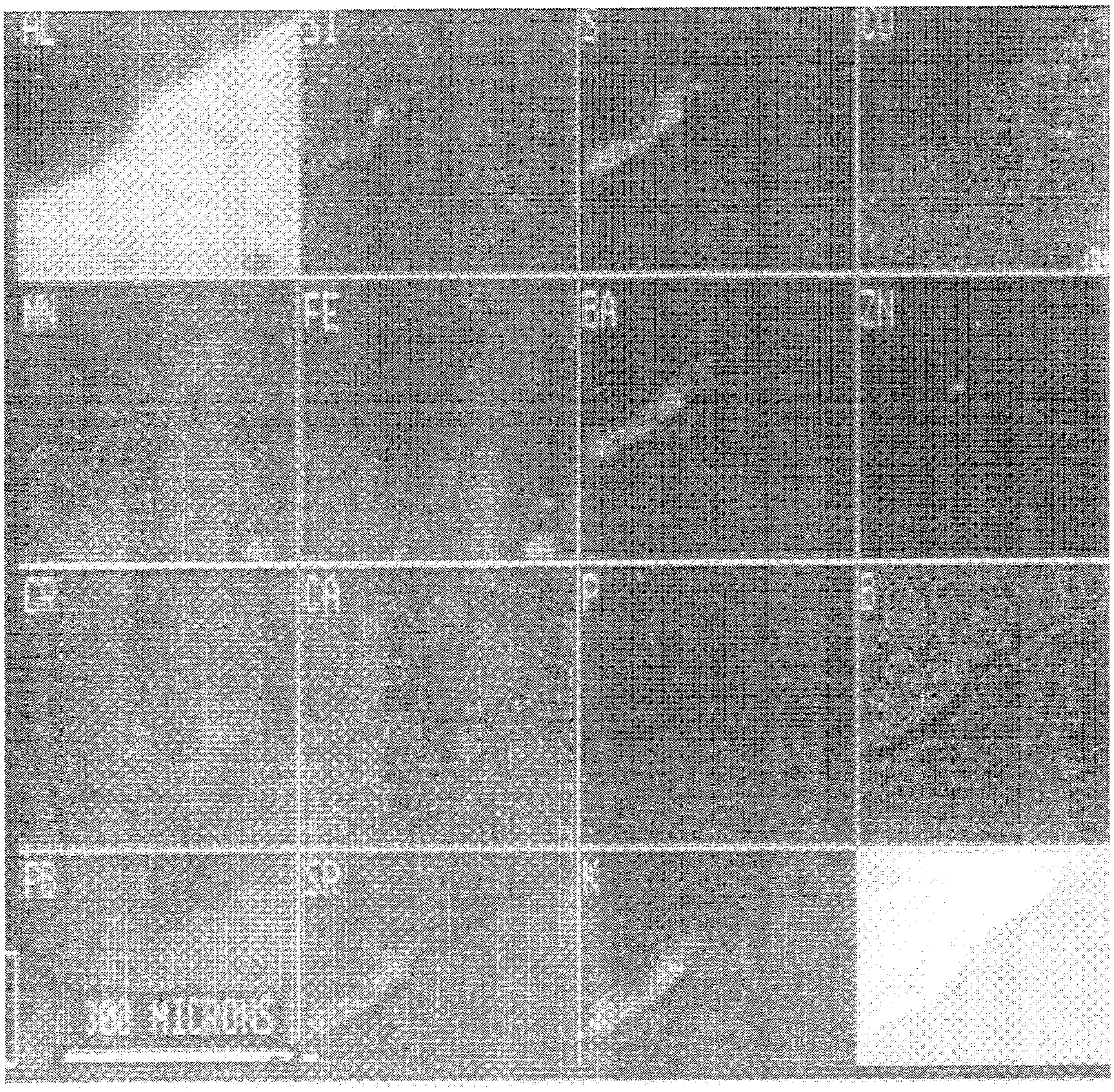

Figure 276. SEM elemental maps showing a cross sectional view of the side of an 800 μm diameter defect in an Epoxy 1 coated CCC Al panel exposed to BaBor saturated 0.01 M K_2SO_4 for 2 months.